A STUDY OF THE APPLICATION OF MAGNETIC FIELD IN HOT MACHINING

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AUGUST, 1978

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A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

by

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to the

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

AUGUST, 1978

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CERTIFICATE

Certified that this work entitled "A Study of the Application of Magnetic Field in Hot Machining of En-24 Steel" has been done by Shri V. Raghu Ram under my supervision and has not been submitted elsewhere for the award of a degree.

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Aug 30. 1970.

ACKNOWLEDGEMENTS

I am extremely indebted to my thesis advisor Dr. M.K. Muju for his constant inspiration, guidance and freely giving his valuable time for discussion throughout the work.

I am extremely grateful to Dr. G.S. Kainth, for using the experimental set up and also to Prof. A. Ghosh and Prof. G.S. Upadhyay for useful discussions and suggestions of the work.

My sincere thanks are due to technical staff of the department particularly Messrs R.M. Jha, B.P. Vishwakarma, M.M. Singh, D.K. Sarkar, Joginder Singh, B.P. Bhartiya and others for their assistance during the experimental work.

I am grateful to Mr.D.P. Saini for his excellent typing and Mr. Lalta Prasad for duplicating the stencils neatly.

RAGHURAM VIDYALA

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SYNOPSIS

An experimental investigation on wear and friction coefficient of materials like Tungstan Carbide and High Speed Steel is studied. The objective is to examine the possibility of superimposing an external magnetic field while machining under hot machining conditions. Tungstan Carbide tool bits are rubbed against En-24 steel, at various velocities. The influence of magnetic field and heating current on wear of Tungstan Carbide is studied. The results show that in a limited range of velocities and heating currents, the superposition of magnetic field and heating current is advantageous i.e. wear is reduced. The experiments also indicate that friction is getting affected by the heating current as well as the magnetic field.

The present work also indicated that a criteria, for the range of application of magnetic field, as proposed by previous workers can serve as a guide line in deciding whether to apply the magnetic field to a particular situation, or not.

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The Scientific Research Committee of the Organisation for Economic Co-operation and Development has defined wear as 'the progressive loss of substance from the operating surface of a body occuring as a result of relative motion of the surfaces' (1).

Depending upon the nature of surfaces, the environment and the demands of the particular situation wear may be considered to be tolerable or devastating. The complexity of the problem has not rendered it easy to arrive at a comprehensive analytical solution of general nature. Most of the efforts of research workers have gone in providing empirical solution to meet the needs of specific situations.

An important class of wear problems is the tool wear, specifically the cutting tool wear. Cutting tool wear directly determines the process capability as well as productivity of the machining operation. As such, the problem has assumed a significant position among the problems facing the manufacturing industry. Several approaches have been taken up to reduce the cutting tool wear in manufacturing

industry. When machining high strength steels one of the successful techniques is to reduce the shear strength of the work material, locally, near the cutting edge.

Wear studies have still not yielded any comprehensive set of laws basically due to the complex nature of the problem itself. For instance, the wearing behaviour of a pair of interacting solids would in general be governed by factors like:

i) bulk properties

ii) surface properties

iii) material inhomogenity

iv) adhesion and diffusion characteristics of materials.

Apparently, the friction between two rubbing surfaces can play an important role in the wear phenomenon but again there does not seem to be a clear relationship between friction and wear. Increased friction need not always lead to increase in wear rate.

1.2 REVIEW OF PREVIOUS WORK

1.2.1 Magnetic Field and Wear

Metallic wear in the presence of magnetic field seems to have been studied by a very limited number of researchers (2-10). Bagchi and Ghosh (2-3) showed that the flank wear of H.S.S. tools is considerably reduced when machining of mild steel is done in presence of magnetic field.

Muju and Ghosh (4-7) have carried out fairly extensive investigations and their theoretical reasoning seems to be consistent with the experimental results obtained by several workers. They have concluded that the magnetic field, basically, influences the adhesive wear behaviour of the rubbing pair. And, the relative magnetic permeability seems to be the predominant factor. The effect of magnetic field is seen through its influence on the mobility of dislocations. Their main conclusion is that in a rubbing pair the magnetic field is advantageous only for the body with lower magnetic permeability.

Quite recently Radhakrishna (11) has further studied adhesive wear in the presence of magnetic field. He has shown that the magnetic field apparently reduces the activation energy for diffusion at the high rates of strain encountered in machining and rubbing of solids at high speeds. He has further proposed a criteria which delineates the region of operation in which the application of magnetic field is advantageous. The conclusion is that in a rubbing pair, magnetic field is disadvantageous for the body with the higher magnetic permeability. However, the beneficial effect on the body of the lower magnetic permeability is also limited by the following criteria:

$$\frac{\text{Hardness of body of lower magnetic permeability}}{\text{Hardness of body of higher magnetic permeability}} > 0.2$$

This criteria is depicted in Fig. 1. In the present work [illegible]ability of this criteria is examined for the cases of Tungs[illegible] En-24 steel and H.S.S. vs. En-24 steel.

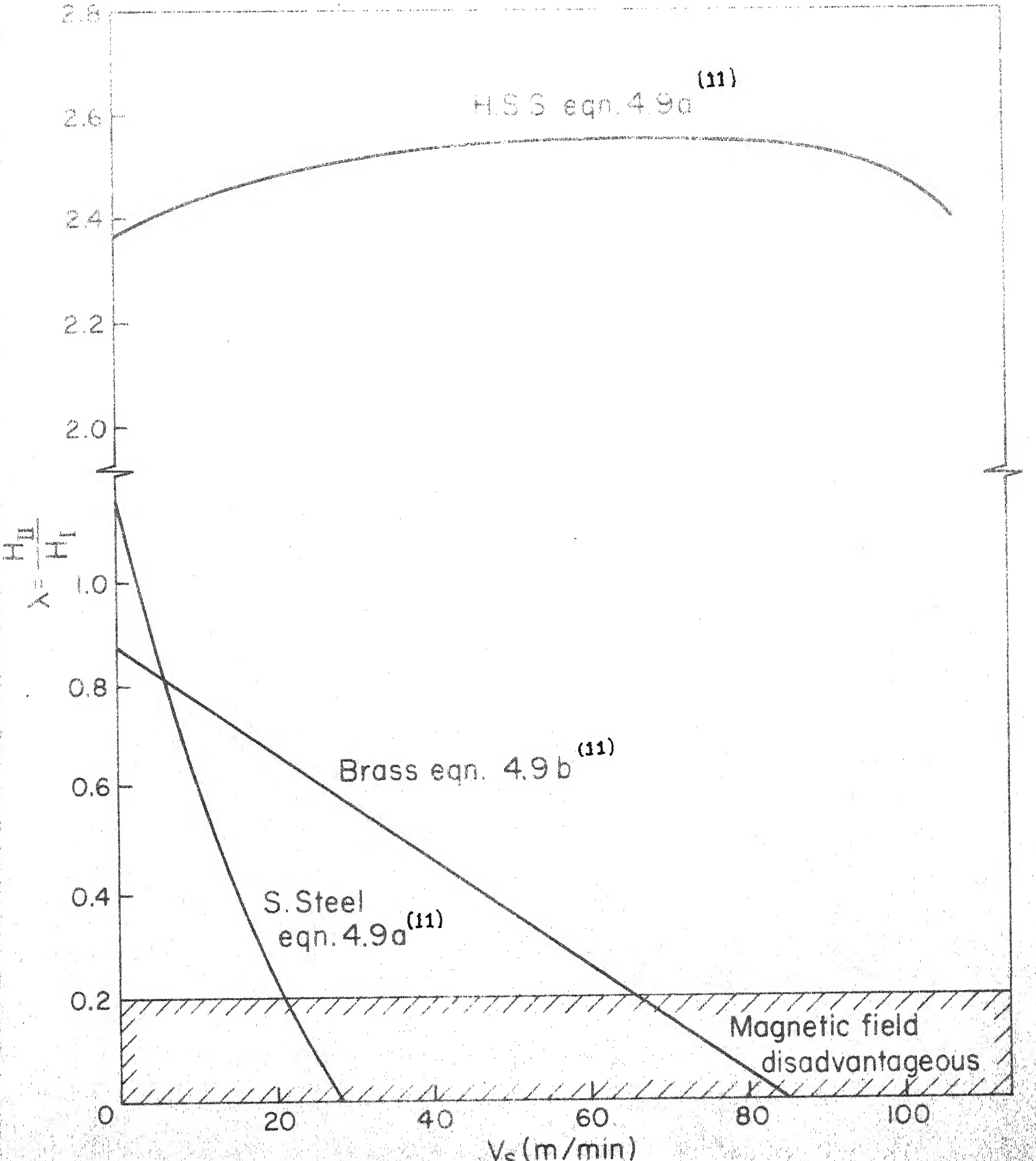


Fig. 1 Variation of hardness ratio with velocity (Temp.)

1.2.2 Hot Machining and Tool Wear

Hot machining is providing a promising line of approach for the machining of high strength, heat resistant alloys [redacted] used in gas turbines, modern aircrafts, missiles and rockets.

The basic idea behind hot machining is to raise the temperature of the workpiece close to the recrystallisation temperature in the vicinity of shear zone. This reduces the tendency of strain hardening. Shear strength of material is reduced with increase in temperature. Fig.1.1 shows the tensile strength of some steels at different temperatures.

Almost all the investigations carried out so far on hot machining can be classified into three main categories i.e.,

a) mechanics of cutting during hot machining

b) tool wear studies in hot machining

c) tool temperatures in hot machining.

Barrow (12) claims an increase in metal removal rate by 200% for a given tool life (Fig.1.2). Tool life and tool wear in hot machining have been discussed in various other papers (23, 24, 25). For optimum tool life improvement, the selection of feeds and speeds is critical. Barrow (22) also found an optimum value of heating current for maximum tool life. He has observed that while cutting En-23 steel at a speed of 350 f.p.m. any heating current between 75 to 175 amperes would result in an increase in tool life of at least 200% (Fig.1.3).

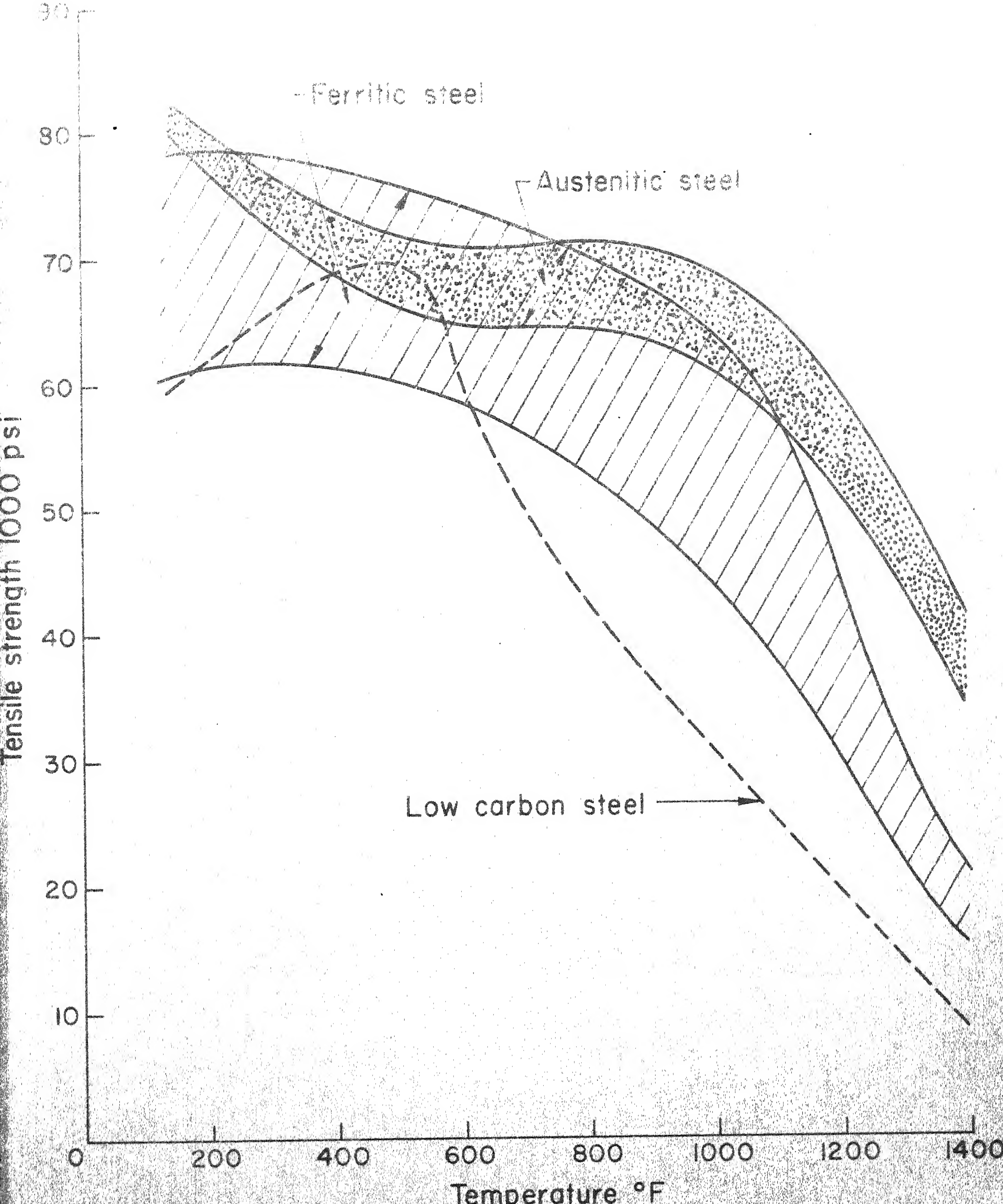


Fig.1.1 Influence of temperature on tensile strength

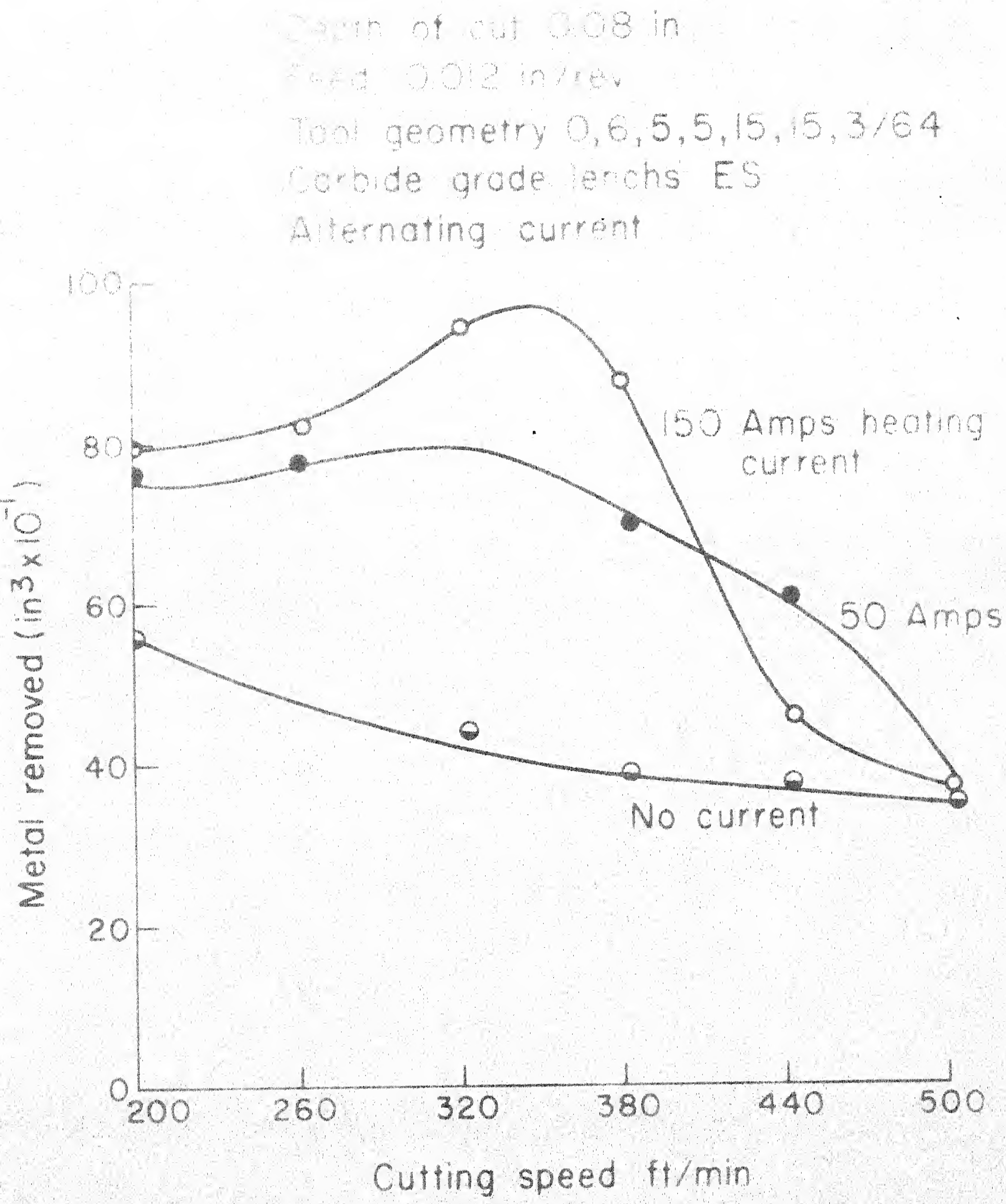


Fig 1.2 Amount of metal removed to 0.01 in flank wear against cutting speed for EN-23 steel (Barrow)

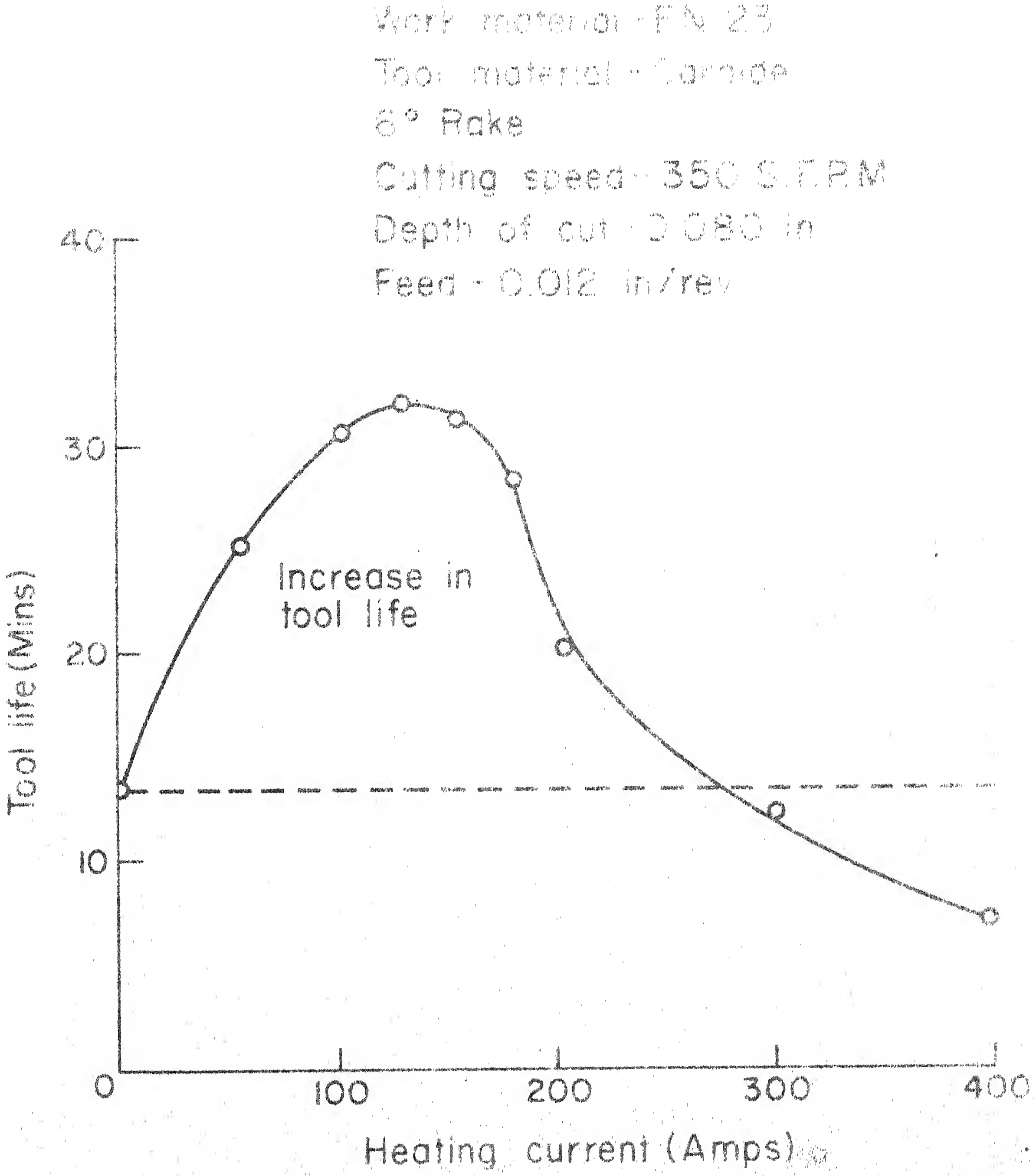


Fig 1.3 Effect of heating current on tool life (Barrow)

1.3 OBJECTIVE AND SCOPE OF THE PRESENT WORK

The discussions presented in the preceeding sections clearly reveal that the tool life can be increased if machining is done either in the presence of magnetic field or under the conditions prevailing in hot machining. Of course, the application of magnetic field is useful only if the tool is having lower magnetic permeability than the workpiece. Since, H.S.S. and Tungston Carbide tools are having lower magnetic permeability than steels it is obviously advantageous to machine steels (including En-24) by these tools in presence of magnetic field.

Since 'hot machining' also reduces the tool wear, a logical conclusion could be that if the magnetic field is superimposed during hot machining, the tool life can be further improved. If at all the combined effect would be additive, the temperature has to be below the curie point, to observe the effect.

The intent of the present work is therefore to see if a low magnitude magnetic field as employed by previous researchers, combined with a low magnitude current in hot machining would yield a satisfactory level of tool life improvement. If this would be achieved then it becomes unnecessary to employ high currents. The low magnetic field low current system would be more economical than the conventional hot machining process, employing high currents.

Another aspect examined in the present work is to find out how the friction between the tool (WC and HSS) and the workpiece (En-24) gets affected both in the conventional hot machining case and in the magnetic field combined with hot machining case. This could help to obtain some better picture about the relation between friction and wear.

CHAPTER II

2.1 TOOL WEAR IN MACHINING

2.1.1 Types of Tool Failure

The failure of cutting tools i.e., when a tool ceases to function satisfactorily may be classified in three general types:

Temperature failure :

When the rate of energy input to the tip of a tool become too large, the tool becomes too soft to function properly and failure ensues. This type of failure occurs quite rapidly, and is frequently accompanied by sparking.

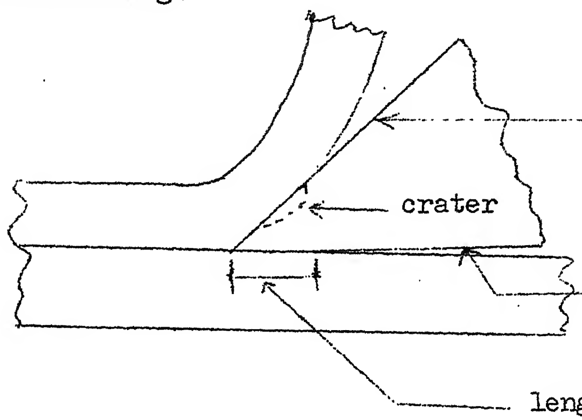
Rupture of the tool point :

Because of the high hardness required, the sharp tip of the cutting tool is mechanically weak and brittle. Whenever the cutting forces exceed a critical value for a given tool, small portions of the cutting edge begins to chip off.

Gradual wear at the tool point :

When a tool has been in use for some time, wear may becomes evident in two regions. These regions are at the rake face and the flank; (Figure shown below). Usually, wear will first appear on the clearance face of the tool in the form of wear land which extends

from the edge along the clearance face. Wear also may be found on cutting tool face of the tool. Here the zone of wear does not extend to the cutting edge, but begins some distance from it. This type of wear is called cratering.



2.1.2 Types of Tool Wear

It is interesting to observe that inspite of the fact that enormous literature on wear is available, it has not been possible to enunciate a set of laws of wear. This is due to nature of phenomenon itself. The most commonly observed wear behaviour is that dry wear will increase with increase in load and velocity. The wear rate is higher for a softer material and lubricant reduces the wear rate. Depending upon the materials and magnitude of parameters involved, wear has been classified in four main groups as:

i) Abrasive wear

ii) Attrition wear

iii) Adhesion wear

iv) Diffusion wear

Generally, at low speeds and low loads, the abrasion wear is predominant while at higher speeds and higher loads, adhesion wear is predominant. At still higher speeds (and temperatures) diffusive wear can be significant.

i) Abrasive wear :

This is the form of wear occur when a rough hard surface, or a soft surface containing hard particles, slides on a softer surface, and ploughs a series of grooves in it. The material from the grooves is displaced in the form of wear particles, generally loose ones.

ii) Attrition wear :

In cutting with hard and brittle tools if the flow of metal past the other metal is more irregular, less streamlined or laminar, a built up edge may be formed and contact with the other metal may be less continuous. Under these conditions larger fragments may be torn intermittently from the surface. Fragments are pulled away, with some tendency to fracture along the grain boundaries. This is called attrition wear. Attrition is not accelarated by high temperatures, and tends to disappear at high speed of metal as the flow becomes laminar, due to improvement in the plasticity of the material.

iii) Adhesion wear :

This is the form of wear which occurs when two bodies slide over each other and fragments are pulled off from one surface after adhesion to the other body. Later, the fragments may come off the surface on which they are formed and be transferred back to the original surface, or else form loose wear particles.

iv) Diffusion wear :

Solid state diffusion is a mechanism by which atoms diffuse from one lattice to another leading to a net transfer of matter from one body to the other one in the direction of the concentration gradient. This is possible, however, only when temperature conditions are favourable for atomic movement. Thus, if in the adhesion process localised temperature increases to a considerable level, interfacial diffusion can occur.

Diffusion wear has been seen to be of a particular significance in the high speed machining process.

Wear has also been observed to occur due to fatigue conditions, fretting, corrosive conditions, etc.

2.2 THERMAL ASPECTS IN WEAR

In the case of ideal adhesion, the strength of bonding at the point of adhesion is often so great that while attempting to free the surface, separation may not take place along the original surface. The bond might fail in such a manner that the fracture occurs in one of the bodies resulting in metal transfer and subsequent removal.

The primary cause of this transfer, according to Burwell and Strang (13), Archard (14), is due to the formation of welded junctions at asperities and their subsequent destruction. Burwell and Strang derived a relationship between wear volume w,

sliding distance L and normal load N (for average normal pressure less than one third of hardness of softer material) as

$$w = C \frac{NL}{P_m} \tag{2.1}$$

where, C = constant, defined as the probability of atom removal

P_m = flow pressure of the softer body.

For average pressure greater than one third of hardness

$$h = C \frac{PL}{P_m} \tag{2.2}$$

where, h = depth of wear

P = average normal stress over the nominal contact area.

The precise nature of the mechanism of particle rremoval is difficult to describe because in all probability a number of processes can take place simultaneously. However, under the influence of the temperature gradient and of stresses and concentration produced during sliding, atoms may diffuse from one material in the other causing corresponding increase or decrease in the weight concentration of the elements in the bodies. With this as on basis, the wear was found to be most approximately related as (15),

$$\frac{W}{LN} \propto \frac{1}{H} \exp\left(\frac{-u}{R\theta}\right) \tag{2.3}$$

where, u = activation energy

R = universal gas constant

θ = temperature of sliding

In terms of sliding velocity V_s , the wear volume rate w as given by Cook and Nayak (16) is

$$w = \frac{V_s NZ}{H}$$

$$= \frac{V_s N Z_o}{H} \exp\left(\frac{-u}{R\theta}\right) \qquad (2.4)$$

Here Z is known as wear coefficient. Equations 2.3 and 2.4 would give the adhesive wear rate for the corresponding body for a given set of conditions.

2.3 EFFECT OF MAGNETIC FIELD ON WEAR

In the expression for wear rate w is given by

$$w = \frac{Z_o N V_s}{H} \exp\left(\frac{-u}{R\theta}\right) \qquad (2.4)$$

where u represents the activation energy for wearing process. This equation can be written as

$$\ln \frac{w}{V_s} = \ln \left(\frac{Z_o N}{H}\right) - \frac{u}{R} \frac{1}{\theta} \qquad (2.5)$$

If a wear experiment is conducted and $\ln (w/V_s)$ is plotted against $1/\theta$ the result should yield a straight line if wear machanism is that of adhesion. For a constant value of N and H the slope of the straight line is given by u/R. This procedure can in fact be used to check i) whether the wear mechanism is through adhesion and ii) to obtain the value of activation energy involved.

Using this procedure Radhakrishna (11) has recently obtained the results of activation energy. The results suggest that the activation energy for wear is less in presence of magnetic field by about 9%. The results also showed that the activation energy involved is close to the diffusion activation energy of iron obtained at high strain rates (17). On the basis of this observation the diffusivity in presence and absence of magnetic field can be written as

$$D_s^H = D_o \exp\ (-u_H / R\theta) \qquad (2.6a)$$

$$D_s^o = D_o \exp\ (-u_o / R\theta) \qquad 2.6b)$$

In these expressions the subscript 's' indicates that diffusivity is estimated in strained condition. Superscripts 'H' and 'o' denote the presence and absence of magnetic field. It can be seen that the ratio of diffusivity is given by

$$\frac{D_s^H}{D_s^o} = \exp\left(\frac{u_o - u_H}{R\theta} \right)$$

$$= \exp\left(\frac{\Delta u}{R\theta} \right) \qquad (2.7)$$

For mild steel rubbing against brass with a constant load of 10 kg, Δu was estimated as 1450 cal/mole. Muju and Ghosh (5,7) had earlier postulated that the ratio of diffusivity could be approximated by

$$\frac{D_s^H}{D_s^o} = \frac{\rho^H}{\rho^o} \qquad (2.8a)$$

$$= \left(\frac{V^H}{V_o} \right)^2 = \exp . \frac{2 V^* G^* \lambda_s}{K \theta} \qquad (2.8b)$$

where, ρ^H, ρ^o = dislocation density with and without magnetic field

V^H, V^o = velocity of dislocation with and without field

V^* = activation volume

G^* = shear modulus

λ_s = magnetostrictive coefficient at any temp. θ°K

K = Boltzman constant

θ = operating temperature

Equation 2.8 was obtained on the basis of a simple arguement that magnetic field would increase the dislocation density and hence, the proportion of vacancies. Therefore at any point in the vicinity an asperity junction the diffusivity would quite probably increase. When equation 2.7 and 2.8 are plotted as a function of temperature, it seems to be in very close agreement to the magnitude of the enhancement of the diffusivity by magnetic field. Using this approach Radhakrishna (11) was able to postulate more strongly that the dislocation activity at the rubbing surface is an important parameter in the wear phenomenon. Subsequently he predicted a criteria for the useful range of application of magnetic field as already mentioned in preceding chapter.

2.3.1 Effect of Hot Machining on Wear

In metal cutting the cutting force (F_H) in the direction of cutting velocity is the largest component. The magnitude of this force can significantly alter the cutting capability of a tool. This magnitude is mainly governed by the strength of the work piece. In machining the cutting force can be approximately calculated as

$$F_H = u a_1 b_1 \tag{2.8c}$$

where, u = energy/unit volume needed ($\simeq$ hardness of the material) in cutting

a_1 = undeformed chip thickness

b_1 = width of the cut.

Using Merchant's force diagram an exact expression for F_H can be obtained. It can be seen that

$$F_H = f\,(\tau_s\,,\ \gamma\,,\ \eta\,,\ \beta\,,\ a_1, b_1) \tag{2.8d}$$

where, τ_s = shear strength of the material

β = shear plane angle

γ = rake angle

η = friction angle

Both equation 2.8c and 2.8d clearly indicate that F_H is a strong function of hardness and shear strength of the work material. Since heating the work piece would lower its strength, the magnitude of the cutting force would decrease. This would result in proportionate reduction in loading on the tool.

Under severe loading even carbide undergo plastic deformation (28). These tools are normally hard but under cutting conditions when the temperature and stresses are high, plastic deformation may cause loss of 'form stability' hence cutting ability. As a result of the inadequate strength of top edge, the sharp cutting edge is deformed and often is 'rounded off'. A further flow of work material over the flank surface changes the clearance angle reducing it to zero or even negative for a certain portion of flank. The amount of bulging and depression of the cutting edge are taken as degree of plastic deformation. Small particles periodically loosened from the effluent material and are carried away with the work piece. However, in order to achieve 'form stability', the condition is given as (28)

$$\frac{Y_s}{\sigma_s} \geqslant 1 \qquad (2.8e)$$

where, Y_s = yield stress of the tool material

σ_s = yield stress of the work material

Since the passage of current in hot machining is aimed at reducing σ_s, the ratio (Y_s/σ_s) will actually increase. Therefore, it is quite possible that the form stability will be maintained (even improved) over a wide range of speed. In short the tool failure will be postponed.

Also while cutting hard steels using carbide tools the chipping of the tool at the edge is observed (22). Hot machining will also reduce this tendency. Cutting a relatively softer material reduces the adhesion wear of the tool because the aspirity junction would fail more often on the side of the work piece. Of course, this depends upon the alloying properties of the material, in general.

2.4 TEMPERATURE MEASUREMENTS

The difficulty of calculating temperatures and temperature gradients near the edge, even for very simple cutting conditions, gives emphasis to the importance of methods for measuring temperature. Several methods have been used for measuring temperatures at the tool work interface. These are

i) calorimetric method

ii) tool-work thermocouple technique

iii) method of moving thermocouple

iv) photographic technique.

In the present work, tool-work thermocouple has been used for measuring the interface temperature. This method employs the tool and work material as the two elements of the thermocouple. The hot junction is the contact area at the cutting edge, while an electrical connection to a cold part of the tool forms cold junction. (In present case mercury bath).

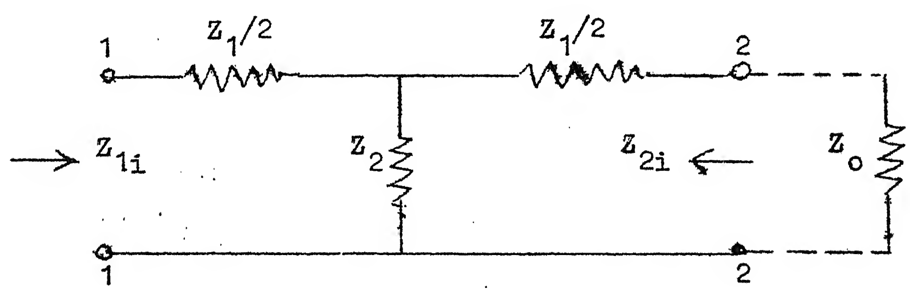
One end of the electrical connection of the heating circuit and the thermal e.m.f. circuit are mating at the tool, there is discrepency due to alternating current (60Hz) which will affect the thermal e.m.f. In order to suppress the a.c. ripples, a low pass filter has been designed and is connected in series with the thermal e.m.f. circuit.

2.4.1 Design of Filter Circuit

Circuits which select relatively narrow bands of frequencies and reject all others are called as resonant circuits. Reactive networks that will pass a relatively wider desired band of frequencies while almost totally suppressing other bands of frequencies are called filters. A circuit that allows only very low frequency to pass are called low pass filter.

Since in the present work frequencies greater than 60 Hz are not expected, the low pass filter was designed, to suppress the frequencies below 60 Hz down to a designed value of cut-off frequency 0.03 Hz.

Characteristic impedence of symmetrical network is an important factor in deciding the lower limit of frequency cut-off f_c. When the two arms of a T network are equal, the network is said to be symmetrical, as shown figure below



For a symmetrical network the image impedences Z_{1i} and Z_{2i} should be equal. Therefore the condition to be satisfied for symmetry is

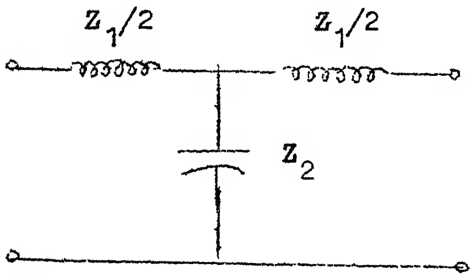
$$Z_{1i} = Z_{2i} \tag{2.9}$$

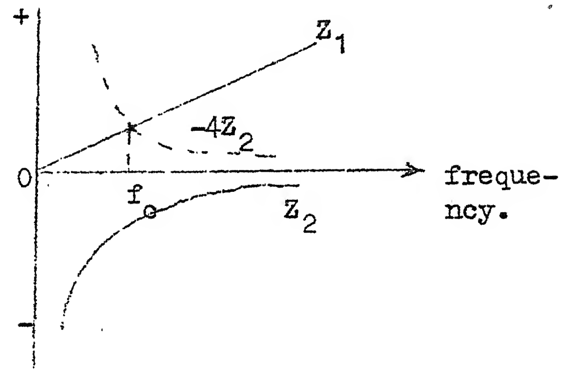
This value of image impedence is known as characteristic impedence or iterative impedence Z_o.

For a symmentrical T section network, total impedence is given by

$$Z_{OT} = \sqrt{\frac{Z_1^2}{4} + Z_1 Z_2} = \sqrt{Z_1 Z_2 (1 + \frac{Z_1}{4Z_2})} \quad (2.10)$$

The reactance Z_1 and $-4Z_2$ will vary with frequency as sketched,





The curve representing $-4Z_2$ may be drawn and compared with the curve for Z_1. It has been shown from the Equation. 2.10 that a pass band starts at the frequency at which $Z_1 = 0$ and runs to the frequency at which $Z_1 = -4 Z_2$. Thus reactance curves show that a pass band starts at $f = 0$ and continues to some frequency $f = f_c$ i.e. cut-off critical frequency. All the frequencies above f_c lie in stop or attenuation, band. This network is therefore a low pass filter.

$$Z_1 = -4 Z_2 \qquad (2.11)$$

$$j \omega_c L = \frac{4 j}{\omega_c C}$$

where, $Z_1 = j\omega L$

$$Z_2 = -\frac{j}{\omega_c C}$$

then, $$f_c = \frac{1}{\pi\sqrt{LC}} \qquad (2.12)$$

The present network circuit has been maintained symmentrical such that the voltage drop between input and output is zero, which leads to no drop in d.c. millivolts in the circuit. For a composite(consisting of several T section) low pass filter of resistance R ohms and cut-off frequency f_c, the values of the inductance and capacitance can be calculated from the equations

$$L = \frac{R}{2\pi f_c} \qquad (2.13)$$

$$C = \frac{1}{2\pi f_c R} \qquad (2.14)$$

For a given R and L the cut-off frequency f_c can be calculated from Equations 2.13 and 2.14

$$R = \sqrt{L/C}$$

which will favour zero frequency for low pass filter. In the present work eight T sections have been used in order to minimise the total cut-off frequency.

The values of L and C used in the present filter circuit are as

L = 15 henries

C = 25 mfd.

Cut-off frequency is therefore given by,

$$f_c = \frac{1}{4\pi^2 L C} \qquad (2.15)$$

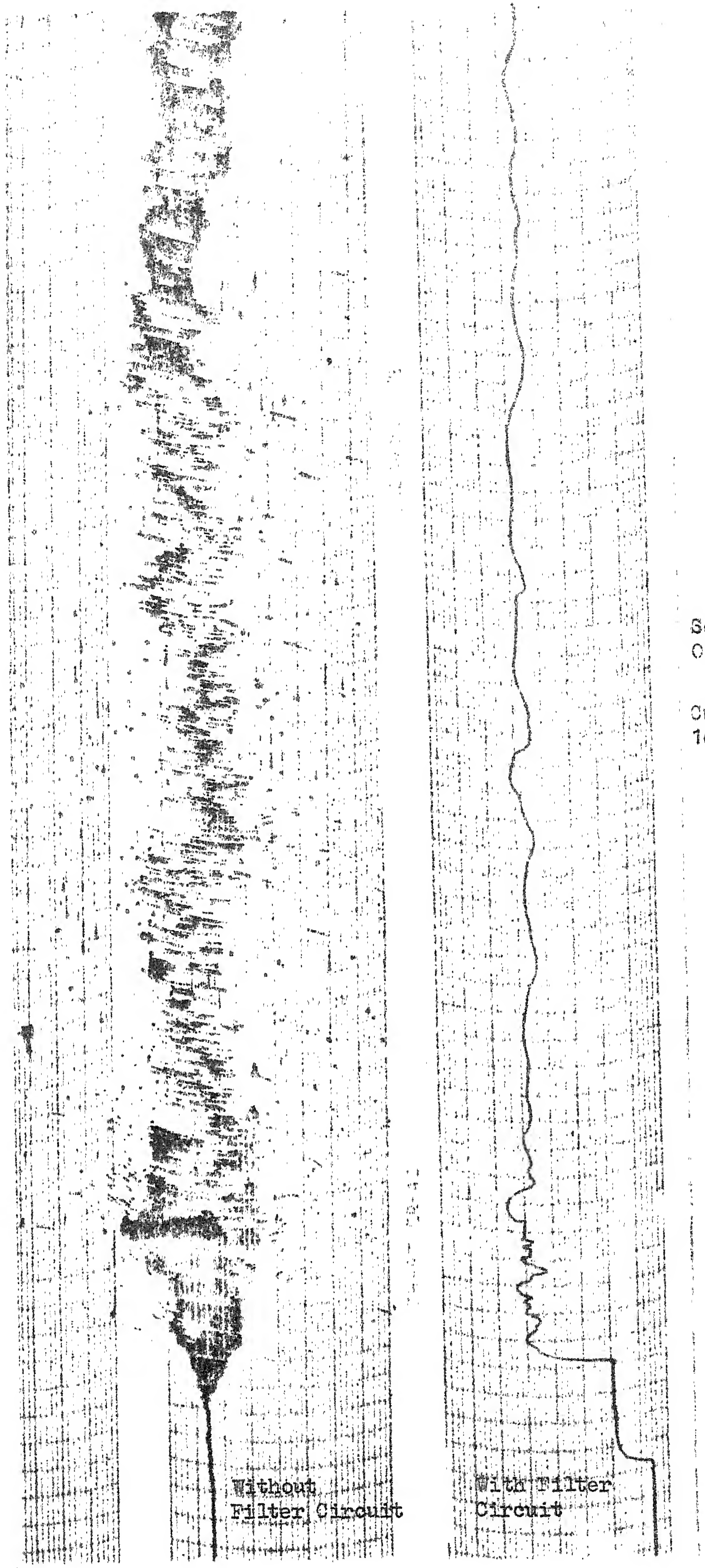
$$= \frac{1}{4\,\pi^2 \times 25 \times 13} = 0.278 \text{ hertz}$$

for eight T sections

$$f_c = 0.0345 \text{ hertz}$$

Since $f_c = 0.0345$ is a satisfactory cut-off value for our purpose the inductance and capacitance of values(13 Henries, 25 mfd) are chosen.

To test the usefulness of the circuit designed in the present work, sample test for temperature was made and is shown in Figures 2.1 and 2.2. It can be seen that the circuit has eliminated the a.c. ripples. Thus the temperature (d.c. e.m.f.) at the cutting tool point could be measured correctly.



Sensitivity
0.005 V/cm

Current
100 amperes

CHAPTER III

EXPERIMENTAL INVESTIGATION

3.1 EXPERIMENTAL PROCEDURE

3.1.1 Introduction

No work on hot machining in presence of magnetic field seems to have been undertaken so far. In order to investigate the possibility of such machining the following experiments were performed in the process of the current work.

1. Dry rubbing of Tungstan Carbide bits against En-24 steel in absence and presence of magnetic field.

2. Dry rubbing of HSS pins against En-24 steel in the absence and presence of magnetic field.

It was found useful to limit the work to the WC.- En-24 and HSS.- En-24 steel combinations primarily because the availability of some data of previous workers and the practical significance of the problem, in manufacturing industry.

In order to perform these tests following instrumentation was required:

1. Resistance heating circuit
2. Magnetic field circuit

3. Temperature measurement circuit

4. Force measurement circuit.

3.1.2 Instrumentation

The block diagram of the experimental set up is shown in Fig. 3.1.* Encardio - Rite recorder was used to measure emf developed in the tool-work thermocouple and the forces developed in X , Y and Z directions. Supply voltage of 5 volts, 50 Hz a.c. was used for the heating purpose. The a.c. heating current causes problems in measuring recording the emf (d.c.) developed at the thermocouple. Therefore, it was found necessary to design a low pass filter circuit to filter the a.c. ripples, as already discussed in Chapter II.

A step down transformer having specification 220/5 volts, 50 Hz, 3 KVA rating, was used to supply high alternating current upto 600 amperes at 5 volts. A voltmeter 0 - 5 volts (a.c.) range was used to make sure that the secondary voltage of the step down transformer remains below the rated secondary voltage. To get various currents, the input to the transformer was varied by using a 'Variac' of 15 amperes capacity.

A current transformer having the turns ratio 1000/5, was used for supplying the required current. The secondary of the current transformer was connected to a 0 - 5 amperes range ammeter.

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* The heating circuit used in the present work was originally designed by Chaudhry (30).

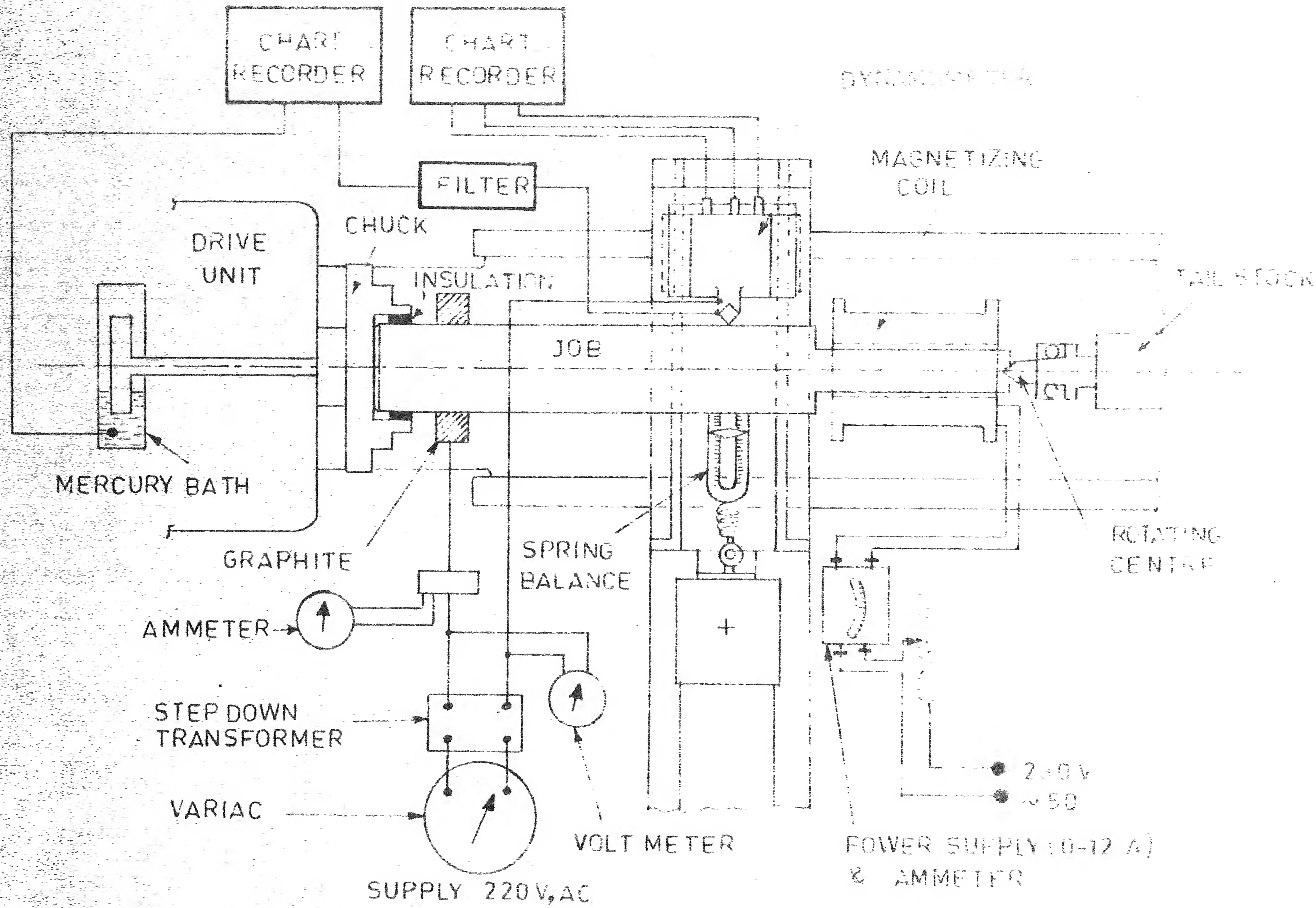


FIG 3.1 Schematic view of the experimental setup

3.1.3 Dynamometer Calibration

A three dimensional dynamometer (Lebow Associates INC, USA), used for force measurements was calibrated directly by applying loads on to the dynamometer. Encardio - Rite four channel recorder was used to record the forces developed due to loads at the tip of the cutting tool. The length of the over hang of the tool holder was noted and kept same for all the tests. With the tool holder fixed, calibrations in three directions were carried out by changing the position of dynamometer. The calibration curves are shown in Fig. 3.2.

3.1.3(a) Tool-work Thermocouple Calibration

The thermocouple calibration for WC - En steel combination was done earlier by Sachadeva (20) using a standard Chromel Alumel thermocouple as a reference. The calibration curve is shown in Fig. 3.2 (a). In the present work the same calibration curve was used for the purpose of temperature measurements at the interface.

3.2. EXPERIMENTAL PROCEDURE

The present work is mainly devoted to the experimental investigation of wear of carbide and HSS, in the absence and presence of magnetic field and also to study the frictional behaviour over a limited range of rubbing conditions.

All the tests were carried out on a 10 H.P., H.M.T. LB-17 lathe. The workpiece material was En-24 steel (1.5% Ni - Cr - Mo steel) bar of 70 millimeter diameter. Throw away carbide tips (ST* 3)

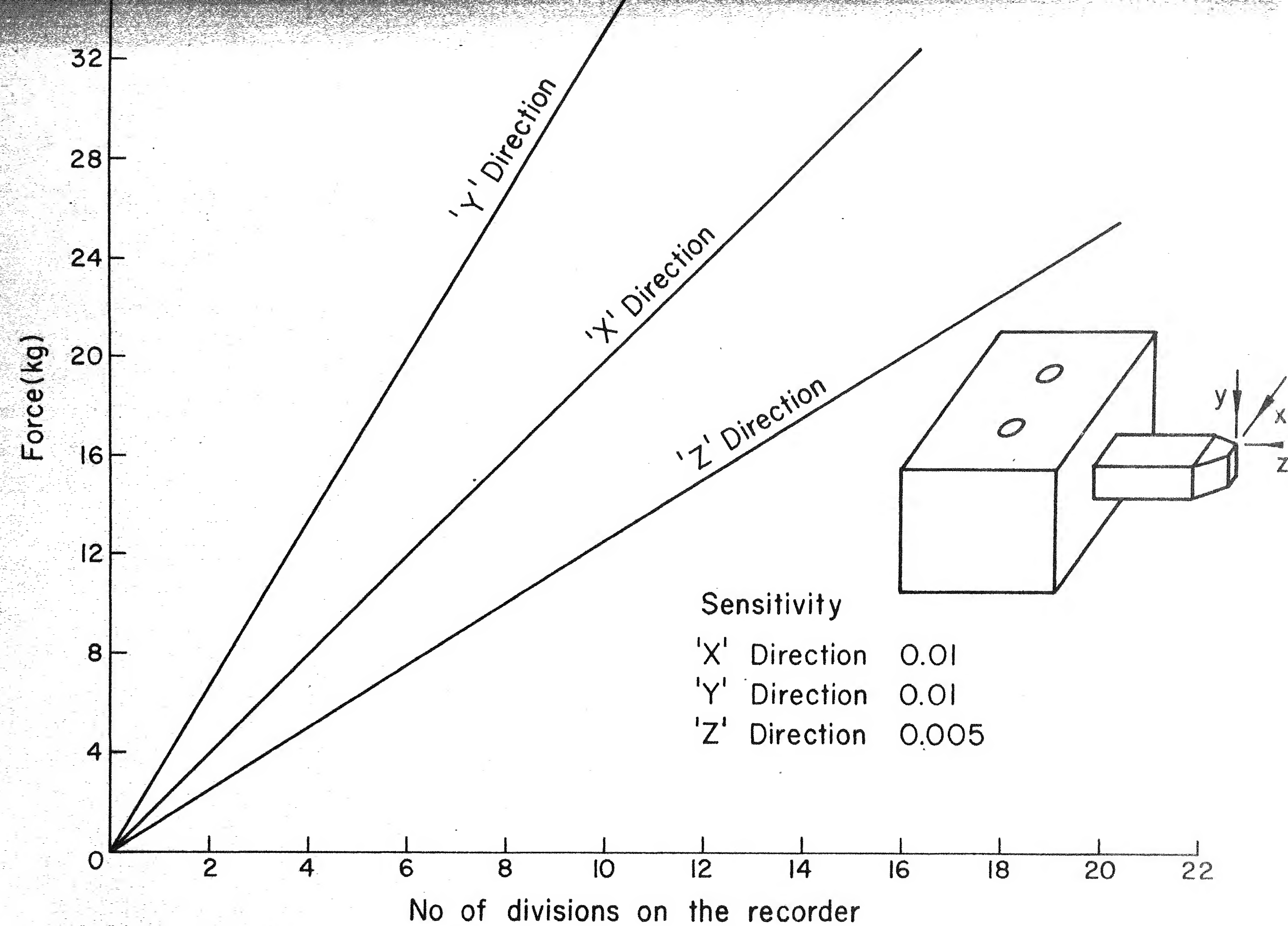


Fig.5 Calibration chart of dynamometer

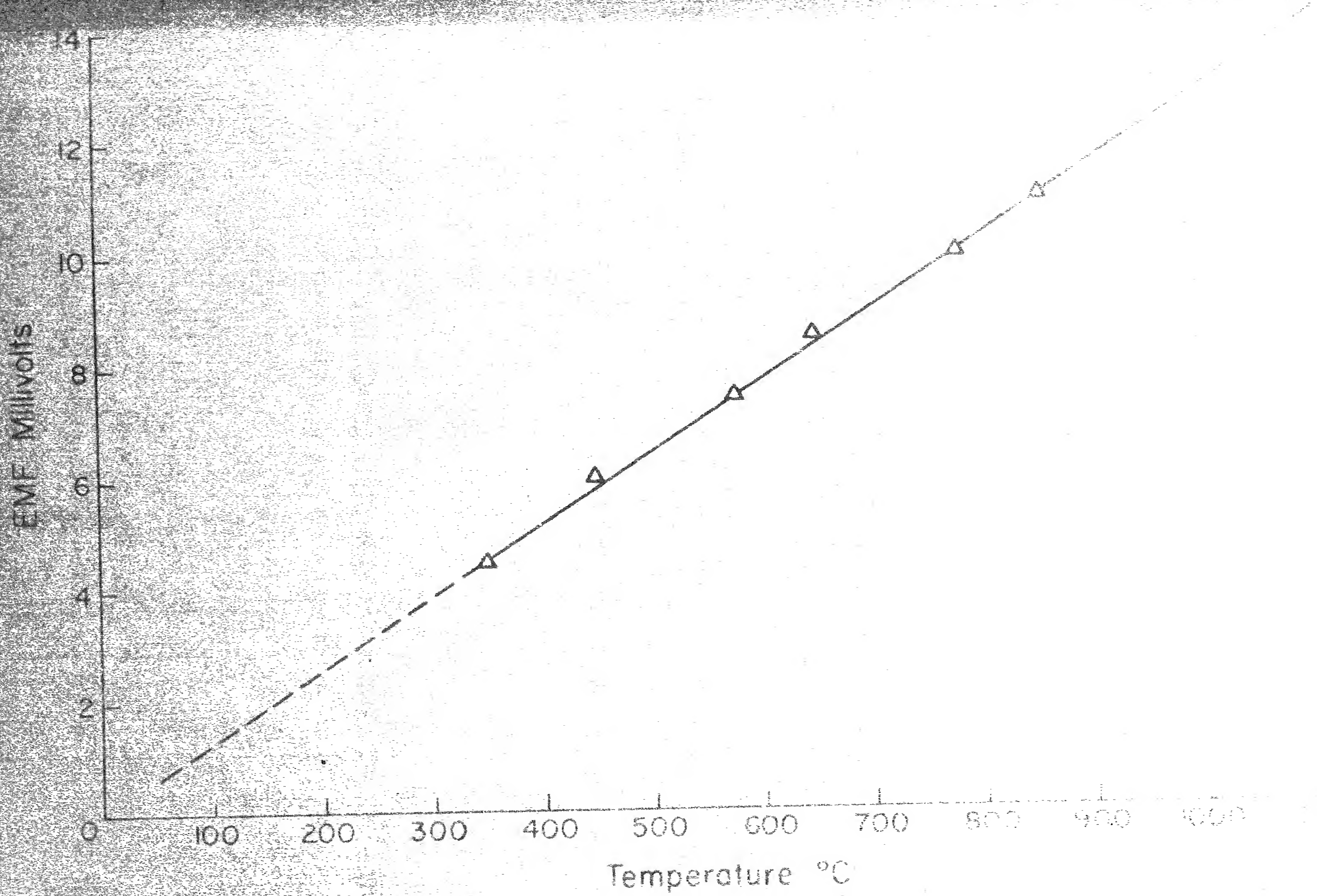


Fig. 3.2(a) Temperature calibration curve for tool work thermo couple (EN-24 vs. wc)

were used for rubbing experiments. These tips are suitable for machining various kinds of steels under unfavourable condition of high temperature. The properties of En-24 steel are given in Appendix (A).

To maintain uniform initial surface conditions the workpiece was machined by a suitable carbide tool and finished by 200 and 320 mesh grade emery papers for all the experiments. The insulation of the tool and workpiece from the lathe was checked by Avometer. The recorder was used to record temperature and forces.

The rubbing of carbide bits over En-24 steel was carried out for ranges of speeds between 32.5 m/min to 132 meters/minute at a feed of 0.05 mm revolution. Investigations were done for heating currents of 50,100 and 200 amperes. All these experiments were repeated for the above speeds, feed and currents in the presence of magnetic field also. Whenever the job was to be magnetised a solenoid designed for the purpose, was energised. The solenoid was put in series with a D.C. power supply which was adjusted to 4 amperes current which can be safely passed through the solenoid. When the rubbing experiments were performed,the radial load was kept constant. A new cutting edge was used for every different speed used. At the end of each test, the tool was cooled by blowing a cold air jet at its tip. This was done to ensure that the tool tip is always at room temperature at the beginning of every rubbing operation as well as to

clear the tool bit. The forces and temperature were recorded for further calculations. The shape of wear scar was elliptical, (Fig. 3.4a).

3.2.1 Rubbing of H.S.S. Pins Over En-24 Steel

Same procedure as used for WC bits was adopted for rubbing of H.S.S. pins against En-24 steel. A special tool holder was designed for this purpose to hold pins firmly. The time of rubbing was adjusted so that the wear scar was of nearly same size in all the experiments. This was done to keep the order of error nearly same at the various measurements. The applied load was maintained constant by means of a spring balance. For friction and wear measurements, the manner of contact between the pin and the workpiece was such that their axes were normal to one another as shown in Figure 3.3. The rubbing was performed at various speeds at a feed rate of 0.05 mm/rev. for various heating currents. Same procedure was repeated, in the presence of magnetic field also. The shape of the wear scar produced on the pins and carbide tip was generally elliptical. This is shown in Figure 3.4b.

3.2.2 Measurement of Wear

Wear measurements were done with the help of MP 320 projector (Carl Zeiss optical projector). A constant magnification factor of 100 was used for all the measurements of WC bits. The length and width of the elliptical scar were measured by incident light method.

Fig.3.4a

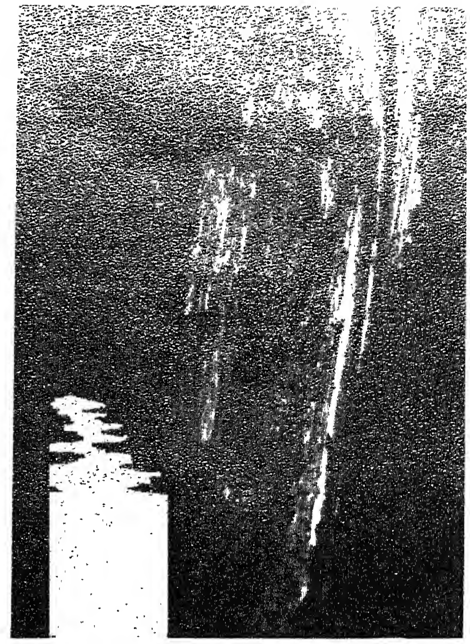
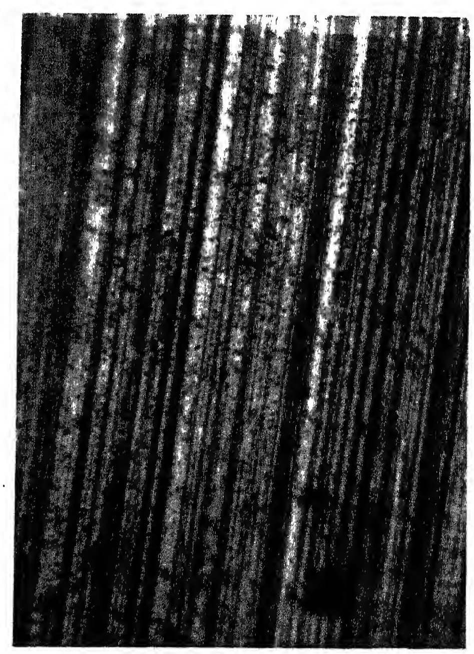


Fig.3.4b

Pitting of H.S.S

Current - 100 Amp



No Current

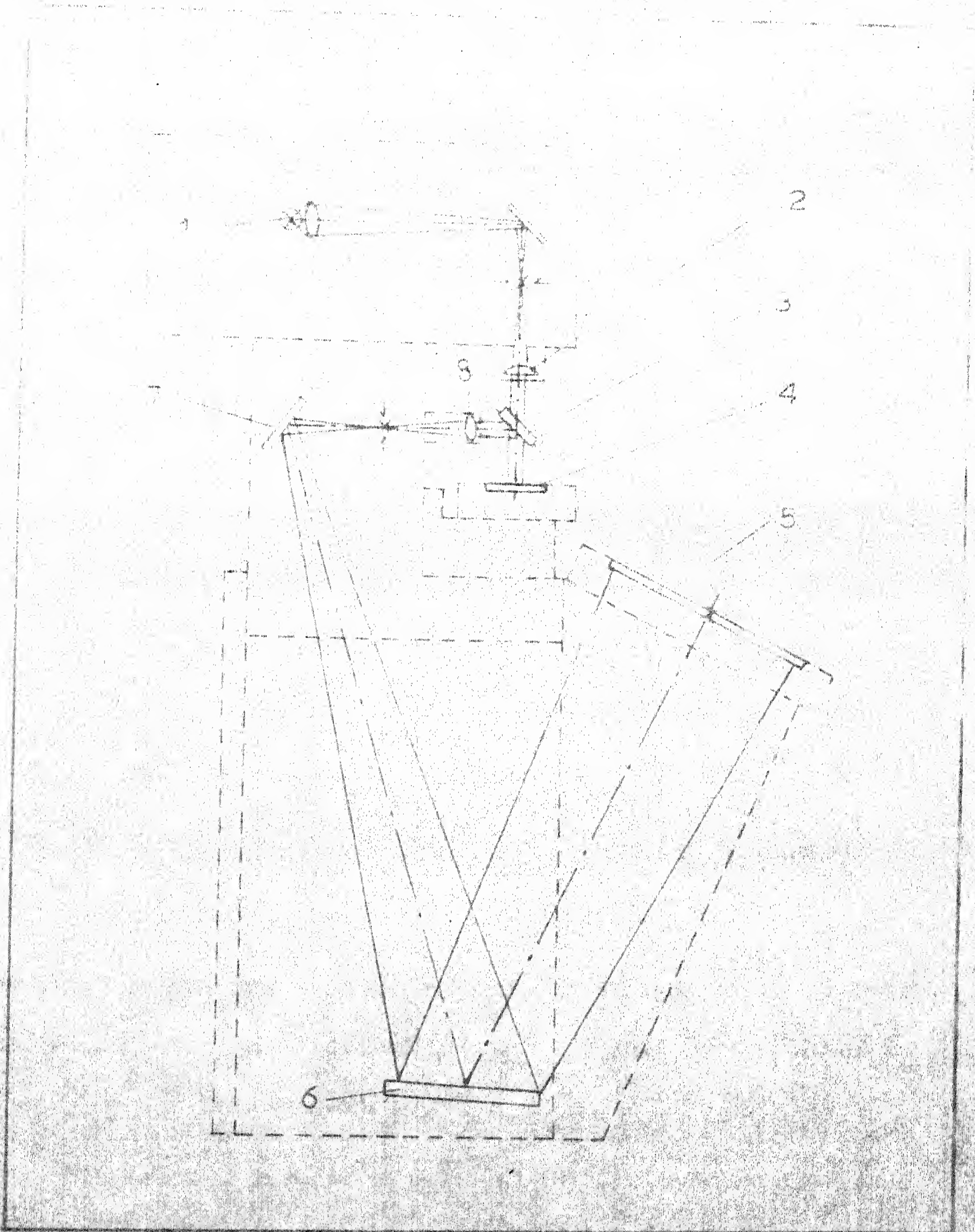
The widest field of application of MP 320 projector in industry is to measure the profiles of the small workpieces, jigs and tools - such as templates, form cutters etc., as well as the ground metal samples. The enlarged image supplies a great number of informations quickly and conveniently. The incident light method is applied for projecting the surface of an object. In such cases, the lighting fixture for incident light projection emits intense light to the surface to be checked. The enlarged image is projected through an optical system to a ground glass screen. The line diagram showing the principle of operation of the projector is given in Fig.3.4. Important specifications of the MP 320 projector used are given below,

Magnifications available	x10, x20, x50, x100
Distortion by objectives	$<$ 0.3 $^{o}/oo$
Distortion by total device	$<$ 0.5 $^{o}/oo$
Diameter of projection face	320 mm
Graduation interval of micrometer screws	0.01 mm

3.3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.3.1 Rubbing of Tungston Carbide Against En-24 Steel under Hot Machining Conditions and also in Absence and Presence of Magnetic Field

These experiments were performed to investigate the variation in wear and frictional characteristics under hot machining and magnetic field conditions. General experimental set up is shown in Fig. 3.1



(1) LAMP (2) UPPER CONDENSER (3) INTERCHANGEABLE MIRROR SEMIPERMEABLE (4) TEST OBJECT SURFACE (5) GROUND-GLASS SCREEN (6)-(7) MIRROR (8) OBJECTIVE

FIG. 3.4 LINE DIAGRAM OF MP 320 PROJECTOR

The solenoid was used to magnetize the job when the experiments are to be conducted in presence of the magnetic field. It was ensured throughout the experimentation that the tool holder and the dynamometer were firmly fixed and not disturbed. Only the tool bit was inserted and removed, whenever required. This was done to ensure consistancy in the location of wear scars, on the tool nose. Also, each test was repeated three times.

In this class of experiments the following measurements were made.

Measurement of the length of wear scar and friction coefficient,

i) under conventional rubbing condition (without magnetic field (M) or heating the workpiece; I = 0, M = 0)

ii) under hot machining condition only (I = I)

iii) when magnetic field (M) is superimposed on the heated workpiece (I + M).

In order to compare the various wear results it was found appropriate to use a constant radial load of 18 kg. This load was estimated in following manner (Appendix-B).

The measured results of wear and friction coefficients are presented in Tables 3.1, 3.2, 3.3, and their graphical variation shown in Figs. 3.5, 3.6, 3.6(a), 3.7.

The results on wear Fig. 3.5 depict the following behaviour:

1. The wear rate (wear/unit time) is generally increasing with increase in rubbing velocity.
2. The wear rate is the highest in conventional case (I=M=0)

3. The application of the heating current to the workpiece has in general reduced the wear. However, the increasing current does not necessarily lead to decreasing wear rate. This can be more clearly observed from Fig. 3.5. Figs. 3.6, 3.6(a) give the gain factor against speed and heating current.

The gain factor has been defined in the same manner as by previous workers (4, 5, 6, 11) and is rewritten as

$$G = \frac{\text{Wear without magnetic field or current} - \text{wear in the presence of magnetic field and current}}{\text{Wear without magnetic field or current}}$$

These figures show that for a particular velocity there is an optimum heating current which yields the maximum gain. This trend is seen for all the speeds investigated. This observation/trend is quite in line with the experimental results of Barrow (12), in the case of machining.

Barrow conducted machining tests on En-23 steel using Tungston Carbide tools and his results are shown in Fig. 1.4. He observed that for the combination of materials investigated, the optimum range of current lies between 75 - 175 amperes. Of course, his results are obtained for cutting tests at a speed of 350 f.p.m. and a feed rate of 0.08inch/rev.

It can be seen from Fig. 3.6(a) that the general trend in the gain curve is the same as obtained by Barrow in machining operation.

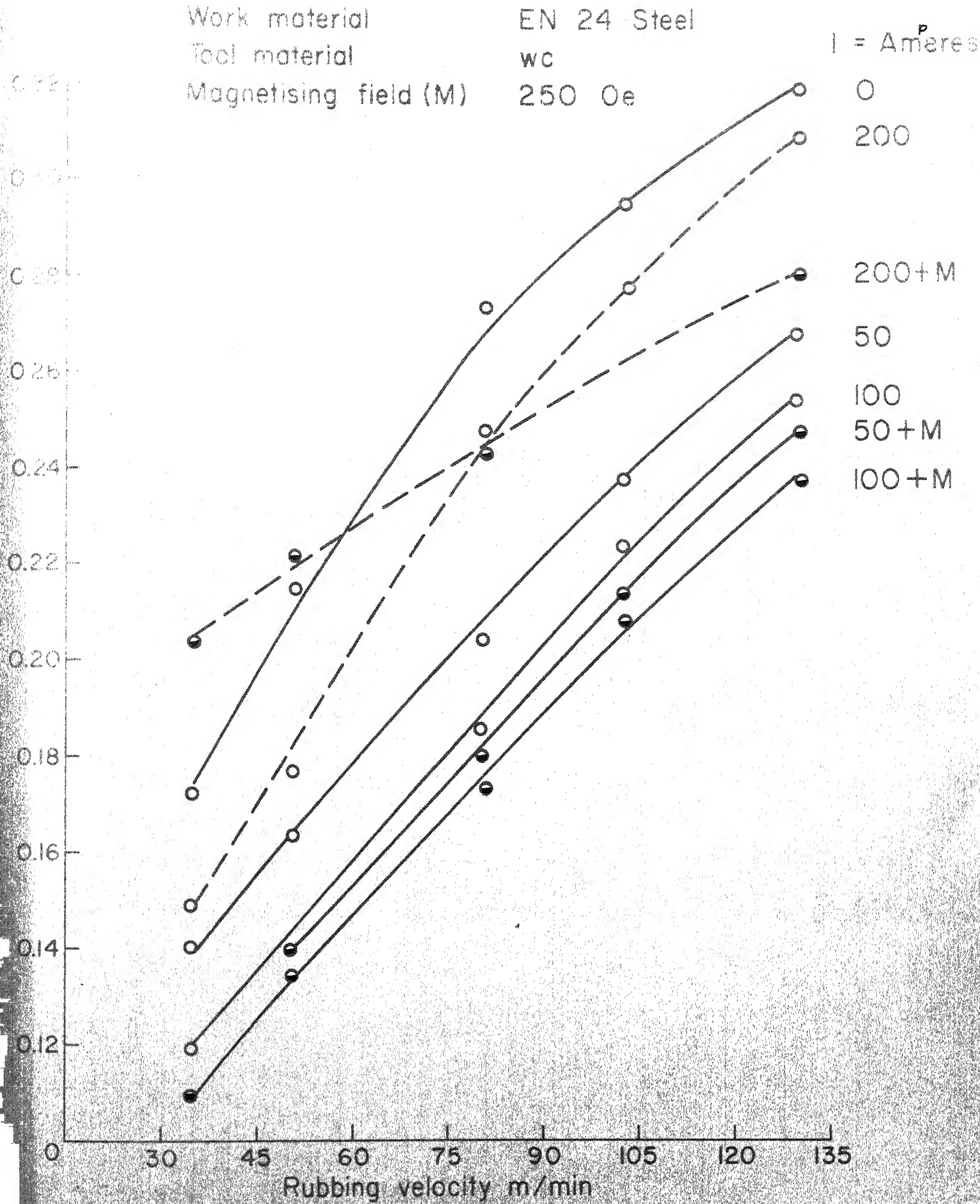


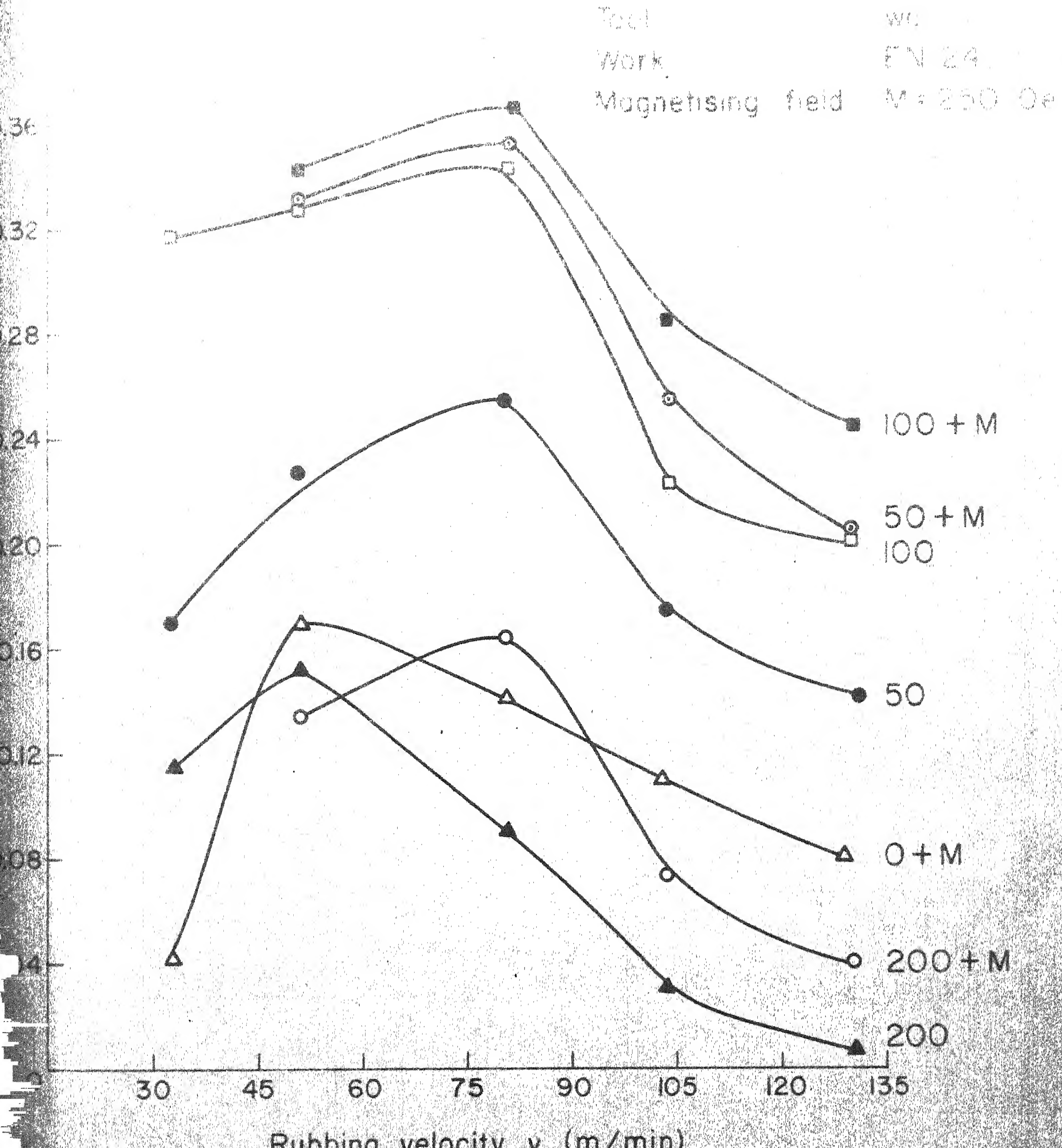
Fig.3.5 Wear of carbide against EN 24 Steel

TABLE 3.1

Rubbing of Carbide against En-24 steel

Feed = 0.05 mm/rev   Magnetic field strength = 250 Oe (M)

Rubbing velocity Vs m/min	Wear rate (length of Scar/unit time) M = 0 mm/min.				Wear rate (length of Scar/unit time) M = M mm/min.			
	I=0	I=50	I=100	I=200	I=0	I=50	I=100	I=200
34	0.1711	0.1420	0.1166	0.1520	0.1642	—	0.1075	—
47	0.2100	0.1620	0.1405	0.1770	0.1733	0.1407	0.1380	0.1820
84	0.2752	0.2048	0.1862	0.2505	0.2318	0.1780	0.1740	0.2308
103	0.2893	0.2388	0.2250	0.2835	0.2562	0.2150	0.2060	0.2680
150	0.3135	0.2734	0.2520	0.3150	0.2600	0.2526	0.2390	0.2750



3.6 Variation of gain factor with velocity in presence of heating current and magnetic field

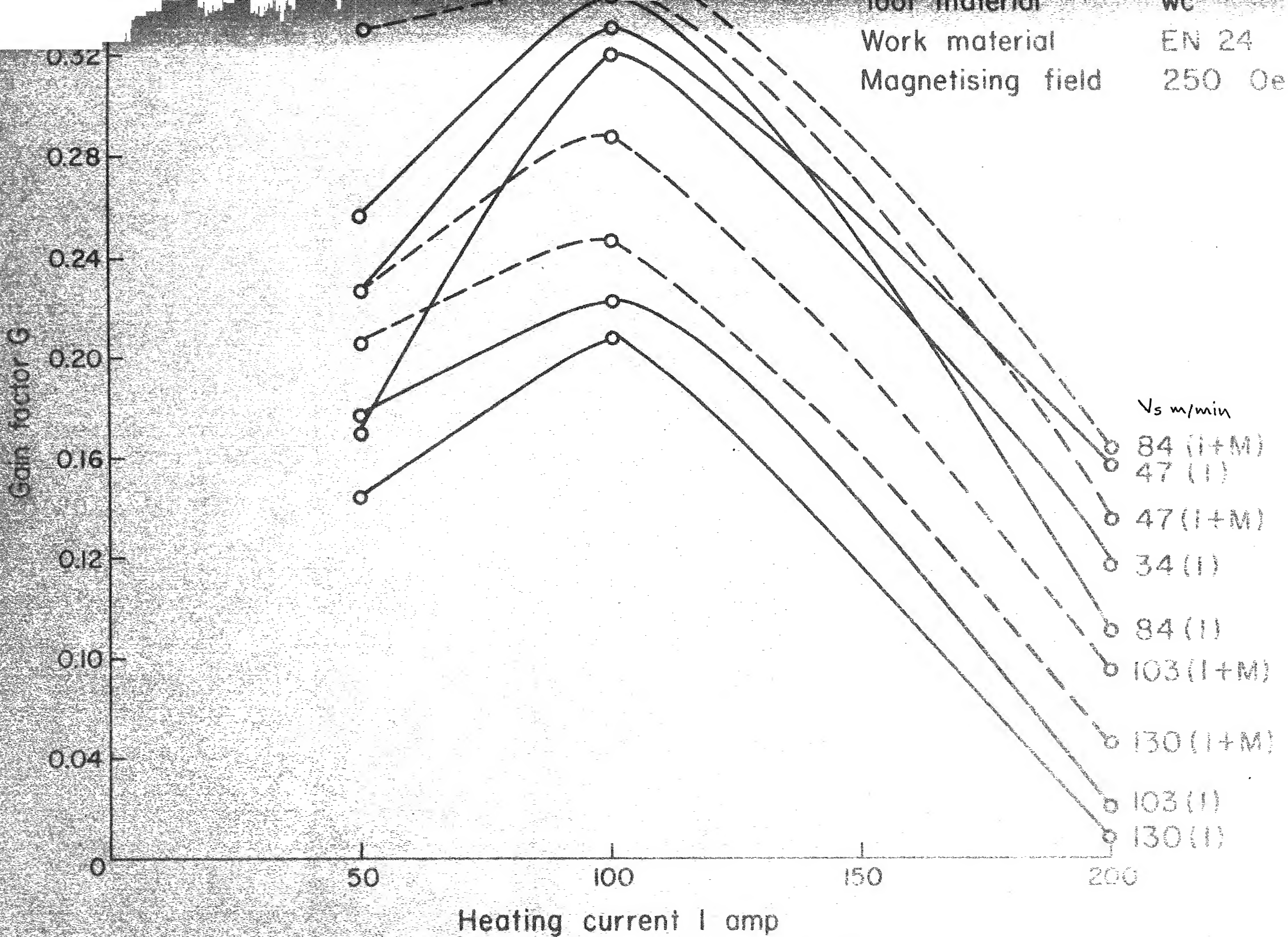


Fig. 3.6(a) Variation of factor with heating current at different velocities

TABLE 3.2

Rubbing of Carbide against En-24 steel

Feed 0.05 mm/rev Magnetic field strength, M=250 Oe

Rubbing velocity	Gain Factor $= \frac{W_O - W_M}{W_O}$ when magnetic field is zero, I amperes 50	100	200	Gain Factor $= \frac{W_O - W_{I+M}}{W_O}$ when magnetic field is applied, I amperes 50	100	200
34	0.170	0.321	0.1116	—	—	—
47	0.2285	0.3305	0.1571	0.33	0.342	0.133
84	0.2558	0.3471	0.09	0.3534	0.3677	0.1613
103	0.1745	0.222	0.0207	0.2568	0.287	0.0736
130	0.1416	0.2087	0.009	0.2018	0.2475	0.044

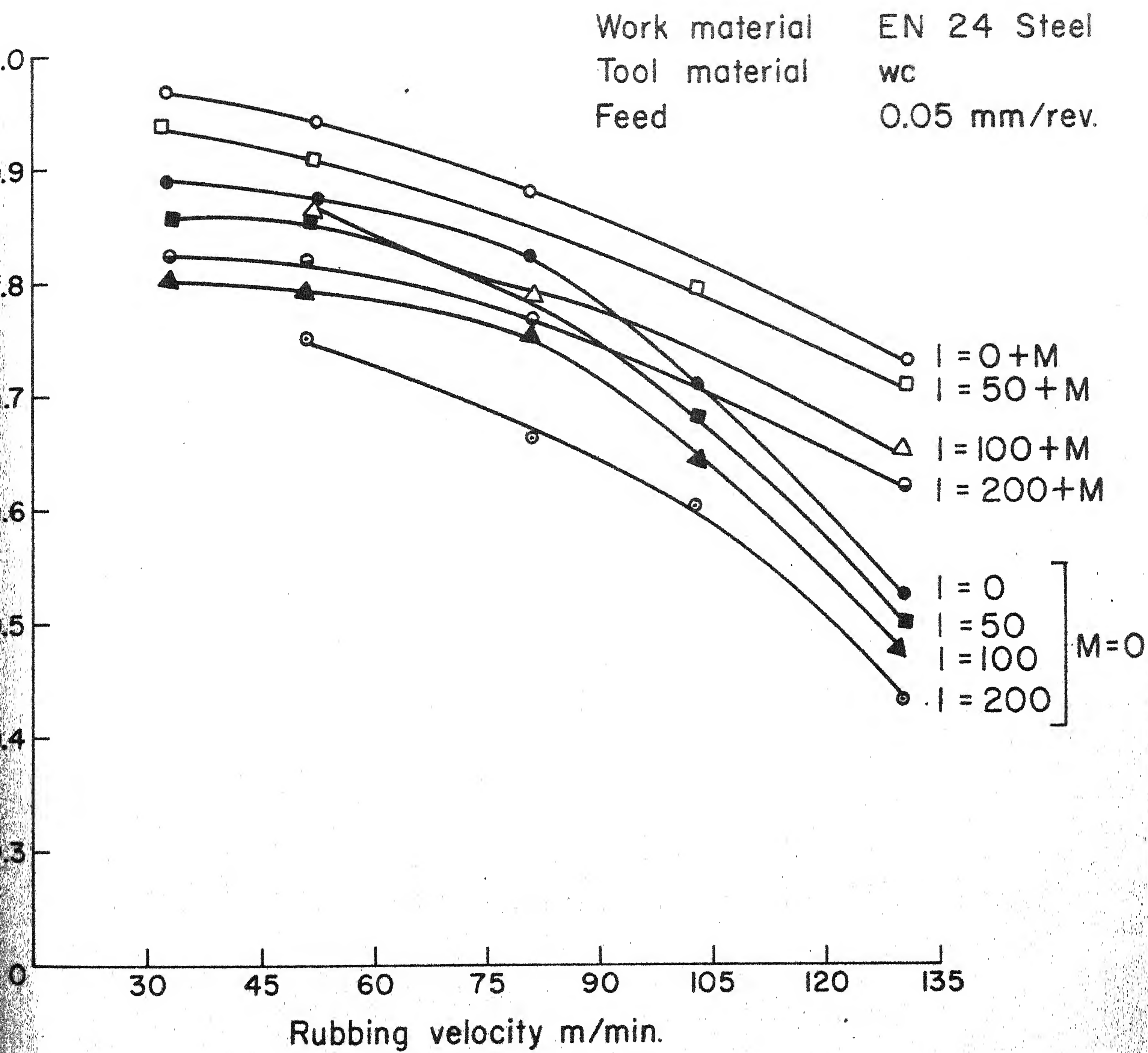


Fig. 3.7 **Variation of coefficient of friction with velocity, at different currents, and magnetic field**

TABLE 3.3

Values of coefficient of friction between En-24 steel and WC bit

Rubbing velocity Vs m/min	Overall coefficient of friction μ (field = 0) I amperes				Overall coefficient of friction, μ (when field is applied) I amperes			
	0	50	100	200	0	50	100	200
34	0.8820	0.8513	0.8035	—	0.983	0.9415	0.8876	0.8486
47	0.8154	0.8160	0.8034	0.7293	0.8936	0.9133	0.8865	0.8280
84	0.7785	0.7918	0.7767	0.6570	0.7850	0.7198	0.7840	0.7836
103	0.6230	0.7325	0.6542	0.6084	0.6540	0.8132	0.77785	0.6774
130	0.5193	0.4964	0.4622	0.4248	0.7394	0.7032	0.7238	0.6339

However, the presence of magnetic field shifts these curves to a higher gain value.

Again, the gain factor does not show a unidirectional increasing trend with rubbing velocity. Actually, the gain seem to be maximum for a speed of about 60 - 84 m/min(and current of 75 - 150 amperes). Thus, it appears that there is an optimum range of both speeds and heating currents in which hot machining yields best results.

Presence of magnetic field seems to create only a general shift towards higher gain and the optimum speed and current remain unaffected. From the gain (and wear) curves another important observation is that a heating current of 100 amps is almost as effective in reducing the wear as a current of 50 amperes applied in the presence of magnetic field. This is an important result as it can result in considerable savings. As an example, the power consumption in the cases can be compared, as shown below

Magnetic field strength M Oe	Electric current amperes I amp	Voltage Volts	Power consumed by electrical ckt. VI volt amperes	Savings in Electrical power
0	I = 100	2.0	100 x 2.0 = 200	-
250	I = 4*	10.0	10 x 4 = 40	
	I = 50	1.2	50 x 1.2 = 60	$\frac{200 - 100}{200} \times 100$
			Total = 100	= 50%

* Magnetising current through solenoid

Thus, while heating current of 50 amperes and magnetic field of 250 Oe is as effective as a heating current of 100 amperes , these calculations show that for the former case there is actually a saving of electrical energy of about 50%. Also, it is seen that a heating current of 100 amperes in presence of magnetic field is better than a heating current of 100 amperes only. Therefore, for the case under investigation, it would be more advantageous to superimpose magnetic field on the heating current of 100 amperes to have further improvement in wear life of the carbide tool. Since in the present case the application of magnetic field is superimposed over the heating current, it is of some interest to estimate gain w.r.t. the hot machining case itself. This is shown in Fig. 3.7(a). In this figure G_{50}, G_{100} represent the gain factor at 50 amperes and 100 amperes. Gain factor G itself being defined as

$$G = \frac{\text{(wear in presence of heating current)} - \text{(wear in presence of heating current and magnetic field)}}{\text{wear in presence of heating current}}$$

As can be seen from this graph for a particular current the magnetic field seems to be more effective, at lower velocities and the effectiveness decreases as the rubbing velocity increases. This behaviour can probably be explained with the aid of Fig. 3.8. This figure shows how the intensity of magnetisation reduces with increasing temperature. At a temperature of θ_c, curie point ($= 770^\circ C$ for steel) the intensity of magnetisation reduces to zero. The fall is however, quite slow

and even at a temperature of $\theta = 0.9\ \theta_c$ ($= 665.7^{\circ}C$) the intensity of magnetisation is reduced only by half. The intensity of magnetisation M, varies with temperature as

$$\eta = \frac{M}{M_o} = 1 - \left(\frac{\theta}{\theta_c}\right)^4 \qquad 3.1$$

where

M = Intensity of magnetisation

M_o = Maximum intensity of magnetisation

θ_c = Curie temperature ($^{\circ}K$)

θ = Operating temperature ($^{\circ}K$)

In order to examine the G_{50}, G_{100} curves in Fig. 3.7(a), the following calculations are done.

Let η_I be defined as the effectiveness factor of magnetisation. Then at any current and speed, η would be influenced by the temperature. If it is assumed that it would be directly proportional to strength of magnetisation, Eq. 3.1 can directly approximate G_{50} or G_{100}.

Table 3.4 shows the calculations of η for the recorded temperatures of rubbing experiments for various speeds. The calculated values of η_{50}, η_{100} are plotted against the rubbing velocity in Fig. 3.7(a).

It can be seen that the trend of fall of η_{50} and G_{50} is rather similar. This closeness indicates that the variation in G_{50} with speed is also, quite likely, primarily due to the variation in

the intensity of magnetisation (or η_I). Also the fall in η_{100} is sharper than η_{50}. This can be simply explained by the existence of higher temperature in the case of I = 100, than in the I = 50 case. The slope of the curve of magnetisation (or effectiveness factor) is proportional to θ^3. So higher temperature would yield higher rate of fall. So η_{100} curve would be sharper than η_{50} curve.

As already discussed in Chapter II, the wear of cutting tools occurs at rake and flank faces, essentially as a consequence of rubbing.

The present series of experiments, have identified that the range of speeds where hot machining is effective is roughly the same for both pure rubbing as well as machining where shearing is a predominant factor. The close similarity in the trend of the gain factor leads to a probable conclusion that in order to test tool life, it may not be necessary to conduct full scale cutting tests over the entire range of cutting parameters. Properly conducted rubbing tests are enough to arrive at the necessary observation, in the first instance. Cutting tests in the range of interest can be conducted after the preliminarly rubbing tests have been conducted. This would lead to considerable savings in material and tools. Chip removal would also be a less significant problem and machining utilisation would be better.

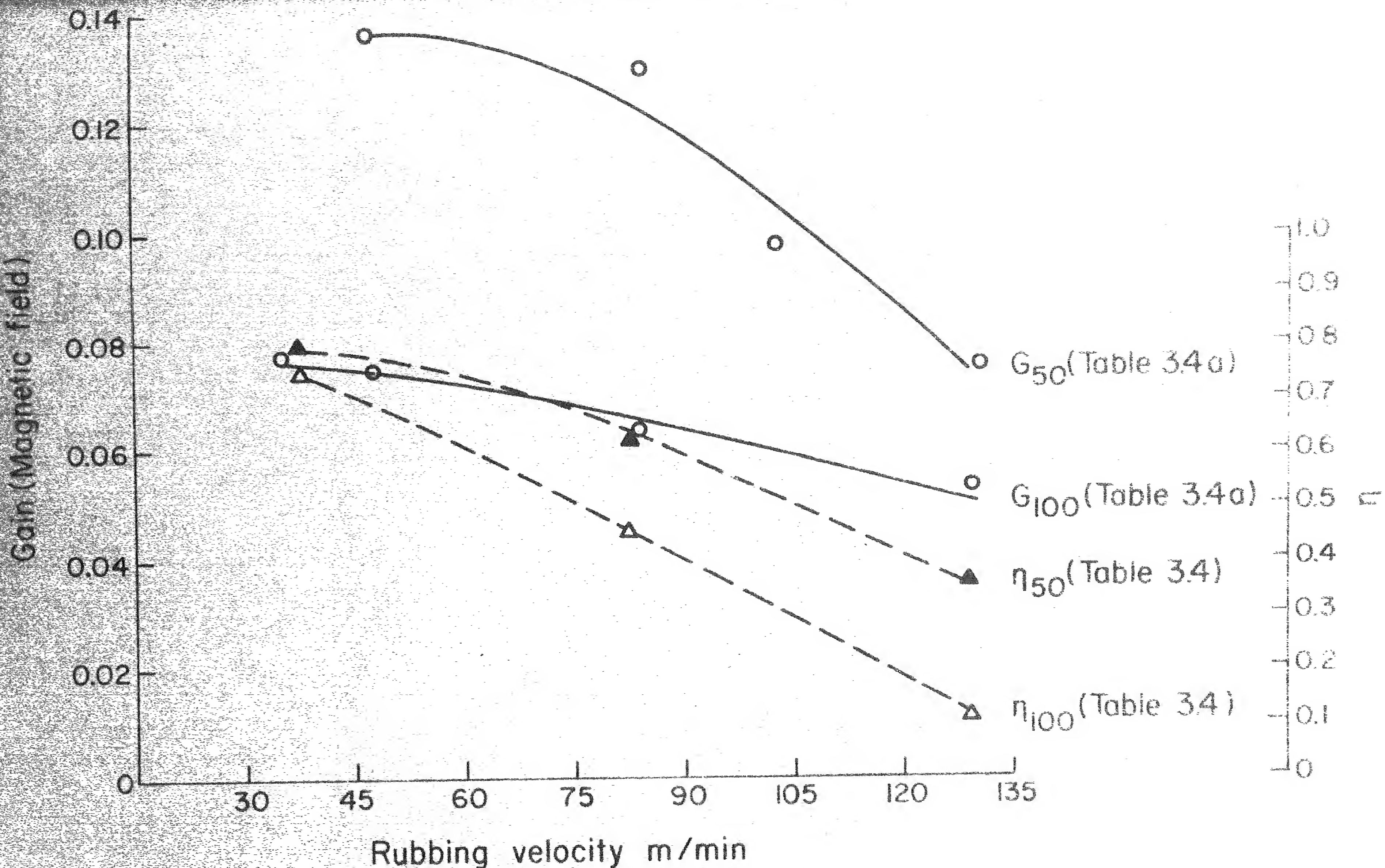


Fig. 3.7(a) Variation of η and G (With magnetic field) against rubbing velocity

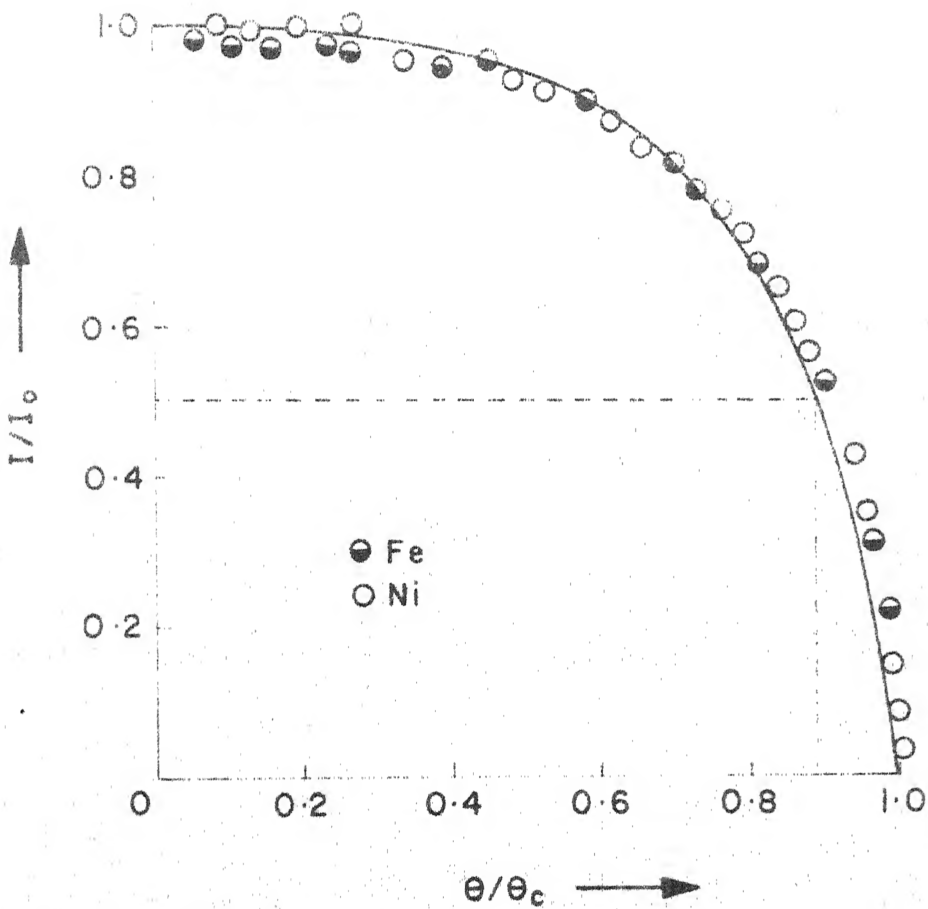


Fig. 3.8 Temperature Dependence Of Spontaneous Magnetisation (101).

It is interesting to see that the trend in the gain curve with the rubbing velocity, in the present work is similar to the trend obtained by previous workers by the application magnetic field. The reasons for the particular trend, in the presence of magnetic field are already postulated by Muju and Ghosh (6,7). They have been able to explain almost all the experiments, based on their model. It is believed that the same mechanisms are operative in the present case also. Of course the interface is at a higher temperature, due to the application of the heating current.

It is suggested (12) that the application of the electric current to the cutting process, creates a thin layer of easy sliding material. This reduces the thickness of the secondary deformation zone, and also the strain hardening. But when the electric input goes beyond a certain limit, the tool chip interface temperature, is raised, and a point is raised when the increased temperature assumes greater importance than the reduction in cutting effort and tool life decreases.

Since the rubbing test as done in the present case, simulate the conditions at the flank, the flank wear in cutting is expected to indicate similar behaviour, since $T \propto \frac{1}{\theta^n}$ $n >> 1$ where T is tool life and θ tool chip interface.

In the present work sparking was observed when a current of 200 ampere was used. Due to the sparking there was pitting and the tool wear was high even with the application of magnetic field. This case was not pursued enough as the wear scar itself was not very consistent.

TABLE 3.4

Curie Temp. θ_c (steel) = 1043°K

Magnetising strength (M) = 250 Oe

Tool: WC

work material: EN24

Rubbing velocity V_s m/min	θ_{I+M} °K I=50 amp.	θ_{I+M} °K I=100 amp.	$\theta^4_{I+M} \times 10^{11}$ I=50 amp.	$\theta^4_{I+M} \times 10^{11}$ I=100 amp.	$\eta_I = 1 - \frac{\theta^4_{I+M}}{\theta^4_c}$ I=50 amp.	$\eta_I = 1 - \frac{\theta^4_{I+M}}{\theta^4_c}$ I=100 amp
34	703	723	2.442	2.732	0.793	0.768
84	818	893	4.477	6.35	0.621	0.462
130	933	1013	7.577	10.53	0.358	0.108

TABLE 3.4a

Values of gain factor with magnetic field and current

Tool : WC

Feed 0.05 mm/rev

Magnetic field strength, M=250 Oe

Work material : EN24

V_s (m/min)	Gain factor $G = (\dot{W}_I - \dot{W}_{I+M}) / \dot{W}_I$ I = 50 amperes	I = 100 amperes
34	0.1358	0.0780
84	0.1308	0.0655
130	0.0760	0.0515

$\dot{W}_I$ = wear rate in hot machining

$\dot{W}_{I+M}$ = wear rate in hot machining in the presence of magnetic field

3.3.2 Friction Measurement Results :

The results of friction coefficient, μ (Fig. 3.7) depict the following behaviour:

1. The friction coefficient is decreasing with increasing rubbing velocity.
2. The friction coefficient is further decreased with heating current and rubbing velocity.
3. In the presence of magnetic field, the friction coefficient is increased.

Mechanism of friction in rubbing is generally explained by the Bowder and Tabor model. Accordingly, the frictional resistance F is defined as

$$F = \tau A_r + P \qquad 3.2$$

where

τ = shear stress required to rupture weld

A_r = real area of contact

P = plowing component of friction force.

If N is the applied load which develops an area of contact A_r, then coefficient of friction is written as

$$\mu = \frac{F}{N} = \frac{\tau}{H} + \frac{P}{N} \qquad 3.3$$

where $N = A_r H$

The reduction in friction coefficient with velocity can be explained in the following manner:

The order of decrease of coefficient of friction should be comparable to the order of decrease of shear strength with temperature. At very high sliding speeds where high values of surface temperature result, friction coefficient will decrease with speed due to the decreased shear strength of the metal.

However, Equation (3.3) shows that the variation in coefficient of friction is primarily equal to τ/H. While both τ and H are measures of the flow stress of metal in shear τ pertains to the surface while H involves the metal in greater bulk. If the system is heated τ and H will decrease. However, the temperature rise that results from increased sliding velocity is mainly on the surface and steep temperature gradient will exist from the surface inward. Therefore, τ will decrease considerably more than H, so that the overall effect of speed (temperature) is to decrease coefficient of friction.

For En steels the overall fall in τ (derived from tensile strength)* from a temperature 240°C (34 m/min) to 700°C (130 m/min) is 52%. The fall in the measured value of μ in the present case is 51.1%. The overall effect of speed on μ is therefore evident.

3.3.3 Effect of Magnetic Field on Coefficient of Friction

As shown in Fig. 3.7 the application of magnetic field has increased the coefficient of friction, under both the conditions i.e., when no heating current is applied and when heating current is applied.

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*Table 3.5a

The limited experimental result of previous workers did not indicate any change in the cutting forces by the application of magnetic field. This was interpreted as not affecting coefficient of friction. It is interesting, however, to see that the friction coefficient is consistently higher at all speeds in the present rubbing tests. It is difficult to explain this behaviour particularly when the higher friction coefficient is existent along with reduced wear.

3.4 RUBBING OF H.S.S. PINS AGAINST En-24 STEEL

3.4.1 Rubbing of H.S.S. Pins Against En-24 Steel under Hot Machining and in Presence and Absence of Magnetic Field

These experiments were performed to conduct limited investigation of the wear (and friction) behaviour of H.S.S. tools in machining. The experimental set up is shown in Fig. 3.1. The H.S.S. pins were ground from a commercial H.S.S. tool of square cross-section in shape. The grinding was done on the lathe, using a special grinding attachment. The experimental procedure was same as discussed in Section 3.2.1.*

The results of wear and friction experiments are presented in Tables 3.5, 3.6, 3.7, and the trend is shown in Figs. 3.10, 3.11, 3.12.

The results on wear Fig. 3.10 depict the following behaviour:

1. Wear rate (wear/unit time) is generally increasing with increasing rubbing velocity.

---

* However, no temperature measurement was done in this case.

2. The wear rate is higher for all the values of current (50 to 200 amperes), than in the case when no current is applied.

3. The application of heating current increases the wear rate of H.S.S. pins. However, there is some decrease in the wear rate by the application of magnetic field.

It is therefore observed that gain is always negative with the application of heating current. However, the application of magnetic field improves the situation. And, gain factor is positive when rubbing is done only in the presence of magnetic field (no heating current). Since the application of magnetic field to H.S.S. in cutting or rubbing of steels has been already found to be advantageous, by several workers (4 - 11) it was not necessary to repeat this aspect any further here.

The real purpose of performing these tests was basically to investigate how the application of magnetic field would affect tool life (of H.S.S. tools) when heating current is also applied. The results obtained in these experiments indicate that it is not at all advantageous to perform hot machining using H.S.S. tools. The application of heating current increases the wear. This problem was not pursued further in the present work because of its obvious practical inapplicability to machining and could not form a part of the present work. However, it is interesting to observe that the application of magnetic field is leading to reduced wear in all the cases.

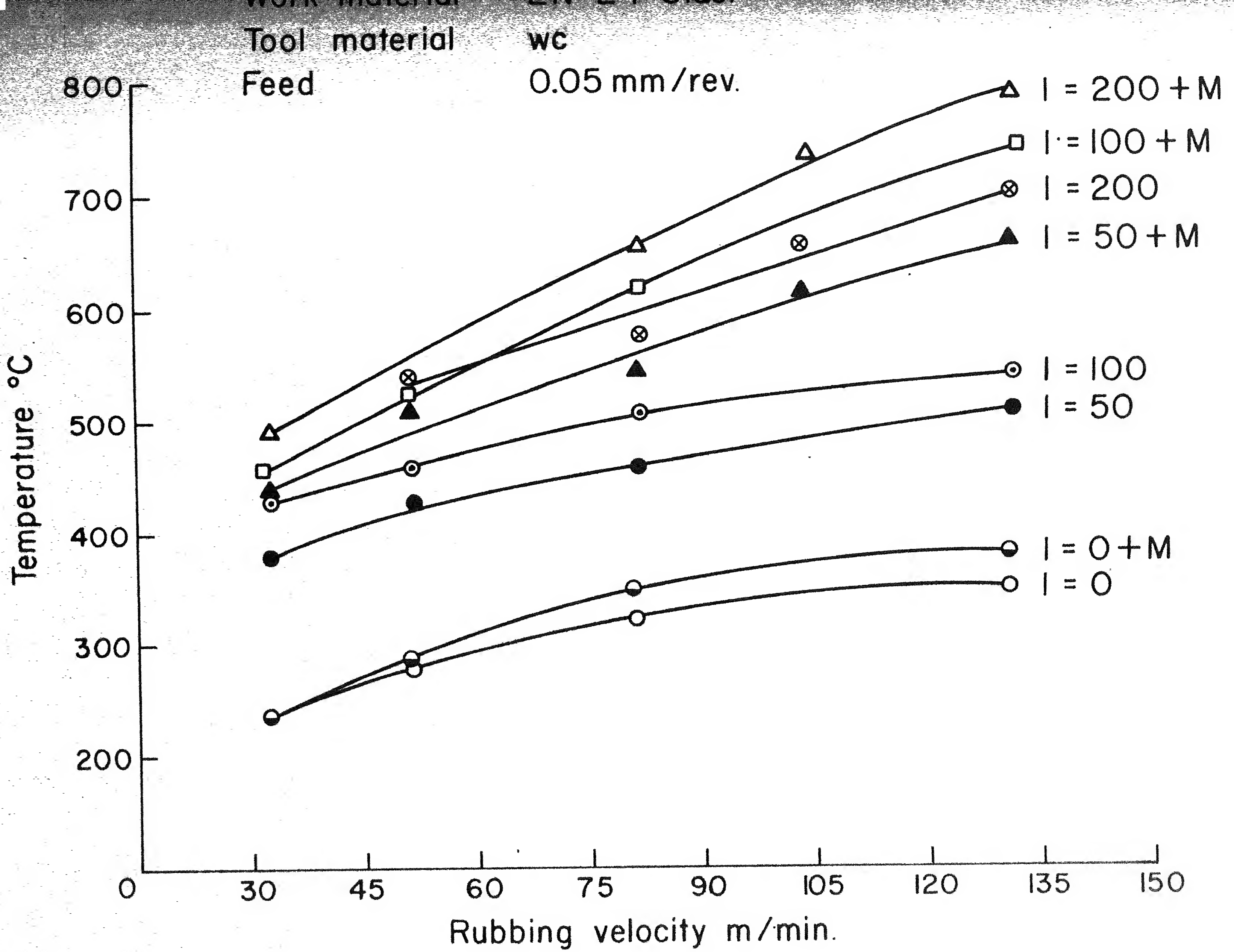

Fig.3.9 Variation of rubbing temperature with rubbing velocity (in presence of magnetic field and heating current)

TABLE 3.4

Measurement of Temperature (WC Vs EN 24)

(Magnetic field strength) M = 250 Oe

Rubbing velocity m/min	Temperature in centigrade (M = 0)				Temperature in centigrade (when magnetic field is applied)			
	I=0	I=50	I=100	I=200	I=0	I=50	I=100	I=200
34	240	380	430	460	250	430	450	490
47	280	430	460	545	290	510	520	545
84	320	460	510	580	350	545	620	660
103	320	480	530	660	360	620	660	740
130	350	510	545	700	380	660	740	780

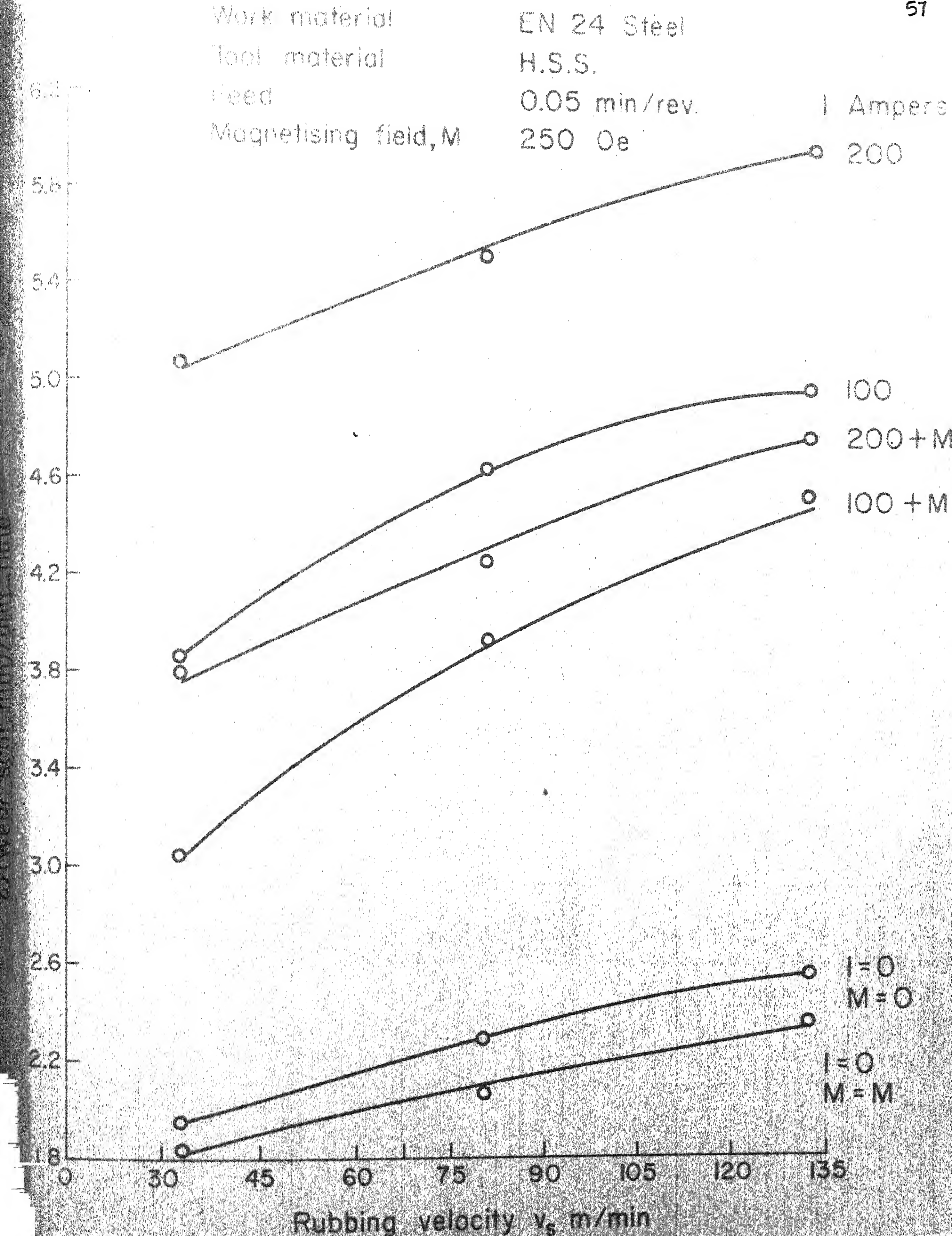

Fig. 3.10 Variation of wear rate with rubbing velocity

TABLE 3.5

Rubbing of H.S.S. pins against En-24 Steel.

Feed : 0.05 mm/rev   Magnetic field strength M-250 Oe

Rubbing velocity Vs m/min	Wear rate mm/min (length of Scar/unit time) M = 0, I = amperes			Wear rate mm/min (length of Scar/unit time) when magnetic field is applied M = M I = amperes		
	0	100	200	0	100	200
34	1.96	3.866	5.08	1.842	3.033	3.80
84	2.28	4.6433	5.525	2.076	3.9633	4.246
130	2.563	4.97	5.96	2.394	4.525	4.7825

TABLE 3.5a

Velocity m/min	Temp. Fig. 3.9	Tensile strength τ Ref. (29) kgf/m^2	μ Fig. 3.7
34	240°C (I=0,M=0)	92	0.8820
.			
.			
.			
130	700°C (I=200,M=0)	45	0.4248

$\Delta\tau = \frac{92.45}{92}$ 52%

$\Delta\mu = \frac{0.8820-0.4248}{0.8820} = 51.1\%$

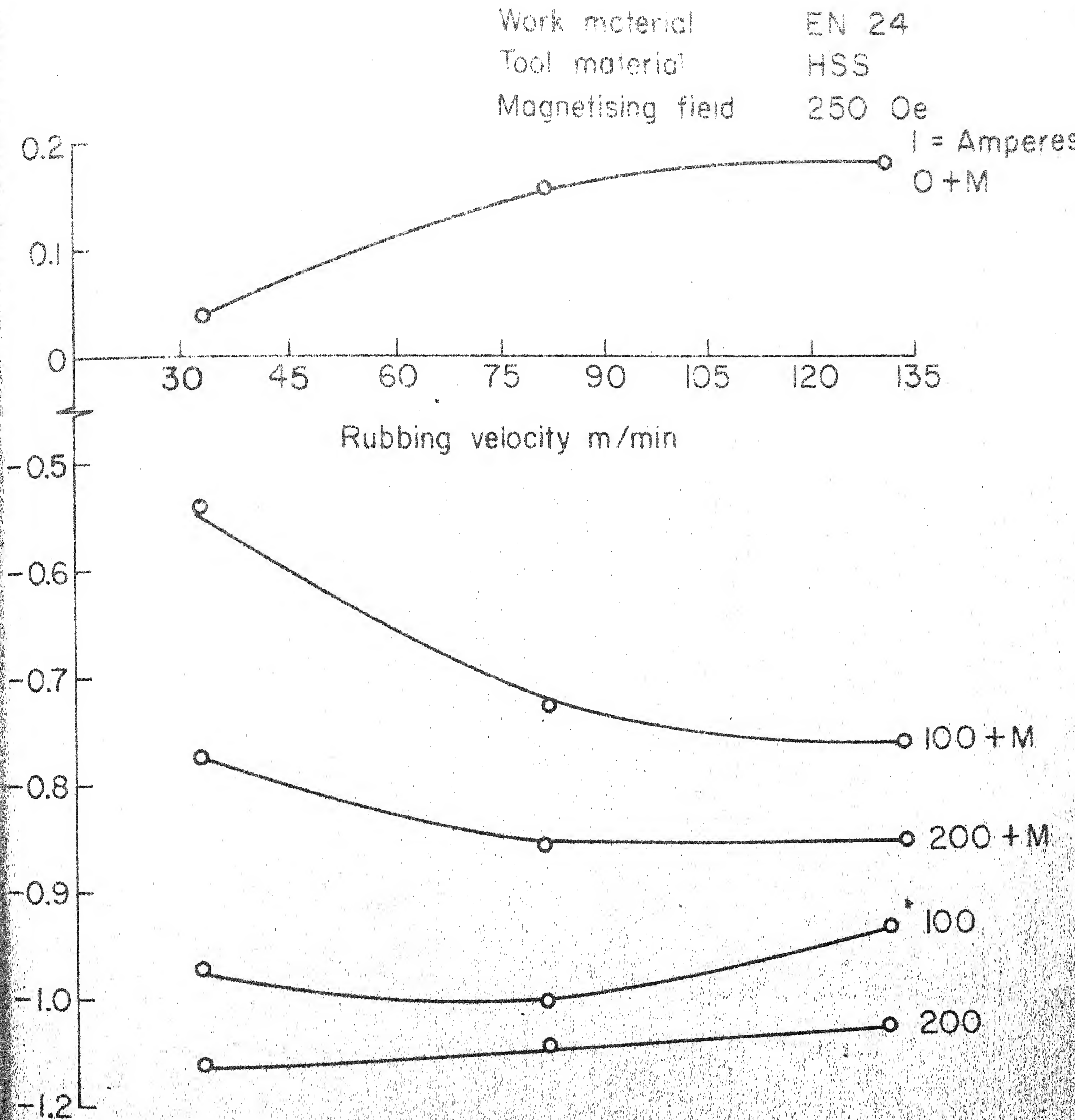

Fig. 3.11 Variation of gain factor against rubbing velocity

TABLE 3.6

Rubbing of H.S.S. Pins Against En-24 Steel
(Gain factor, G)

Feed = 0.05 mm/rev   Magnetic field strength, M = 250 Oe

Rubbing velocity Vs m/min.	Gain factor $= \frac{W_o - W_I}{W_o}$ when magnetic field is zero M = 0, I amps.		Gain factor $= \frac{W_o - W_{I+M}}{W_o}$ when magnetic field is applied M = M , I amp.		
	100	200	0	100	200
34	-0.9724	-1.5918	0.04032	-0.5474	-0.7387
84	-1.0311	-1.4168	0.1577	-0.7337	-0.8573
130	-0.939	-1.3253	0.1836	-0.7655	-0.865

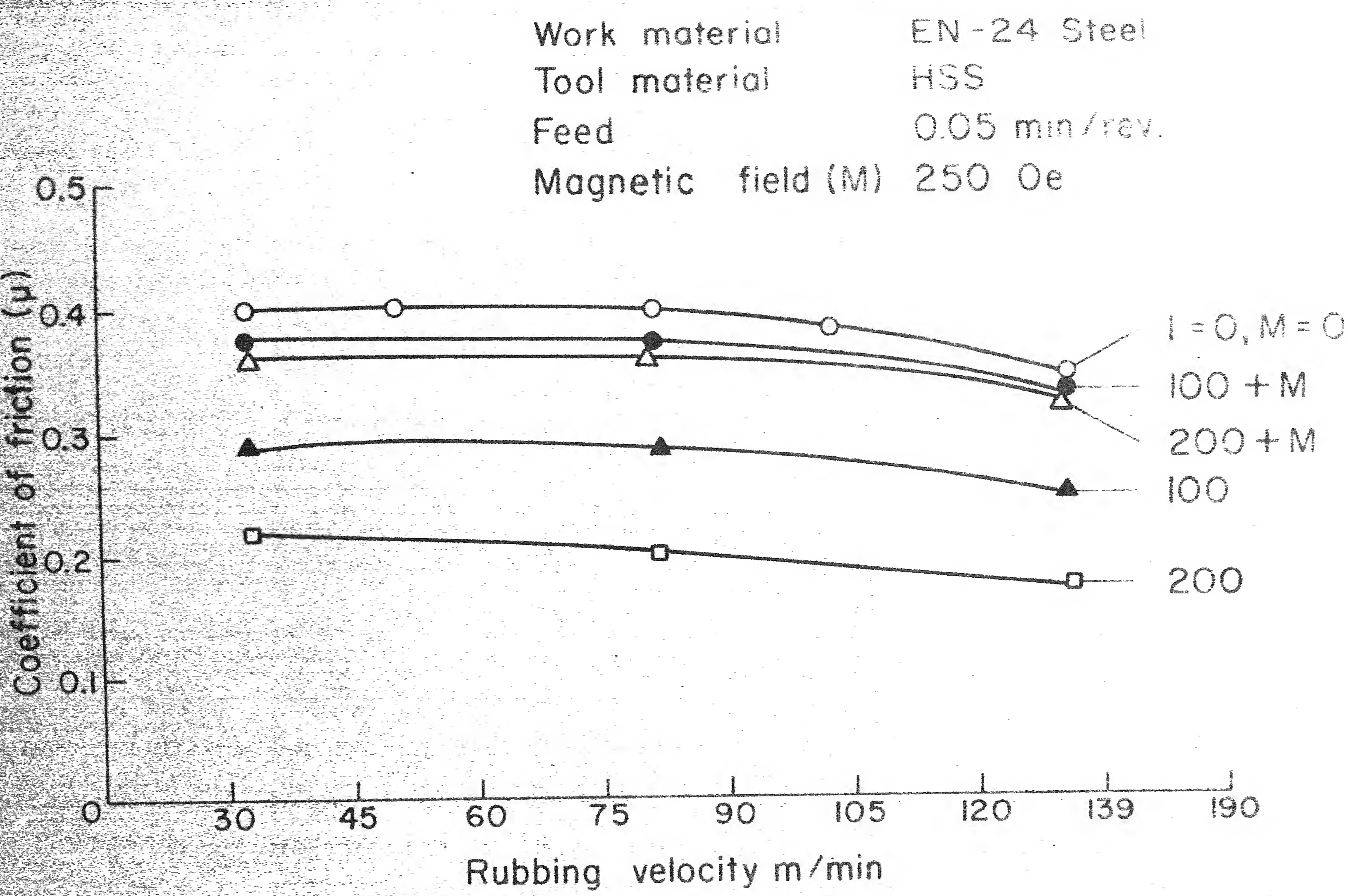

Fig. 3.12 Variation of coefficient of friction with velocity at different currents

TABLE 3.7

Values of coefficient of friction between En-24 steel and H.S.S. pins.

Rubbing velocity Vs m/min.	Overall coefficient of friction, μ (when field is zero) I amps.			Overall coefficient of friction, μ (when field is applied) I amps.		
	0	100	200	0	100	200
160	0.4	0.29	0.216		0.315	0.357
400	0.395	0.2817	0.2		0.375	0.3644
640	0.352	0.245	0.175		0.335	0.338

It is to be mentioned that Radhakrishna (11) conducted rubbing experiments on mild steel against stainless steel and brass. His work predicted that magnetic field will be advantageous only if the following criteria is satisfied:

$$\lambda \text{(Mechanical Interaction factor)} = \frac{H_{II(\theta)}}{H_{I(\theta)}} > 0.2$$

where

$H_{II(\theta)}$ = Hardness of body II as a function of temperature (lower permeability)

$H_{I(\theta)}$ = Hardness of body I as a function of temperature (higher permeability).

He has found this criteria to be satisfied for stainless steel and brass, rubbing against mild steel. On the basis of this criteria he has also predicted that the application of magnetic field should improve the machinability of steel by using ~~steel~~ Tungstan Carbide and H.S.S. tools. The case of H.S.S. tools cutting, rubbing against mild steel has been investigated by Ghosh and Bagchi (3) and their results are in consistent with this criteria. Fig. 3.13 shows the ratio of hardnesses of WC, En steel and HSS. Obviously $\lambda > 0.2$ at various temperatures.

Therefore the present work further strengthens the earlier criteria, as it is seen that for all the cases of Tungstan Carbide rubbing against En steel, the gain factor G is positive, while $\lambda > 0.2$.

On the basis of these experimental findings it is strongly recommended that machining tests be done to establish the exact range of advantage of magnetic field in hot machining.

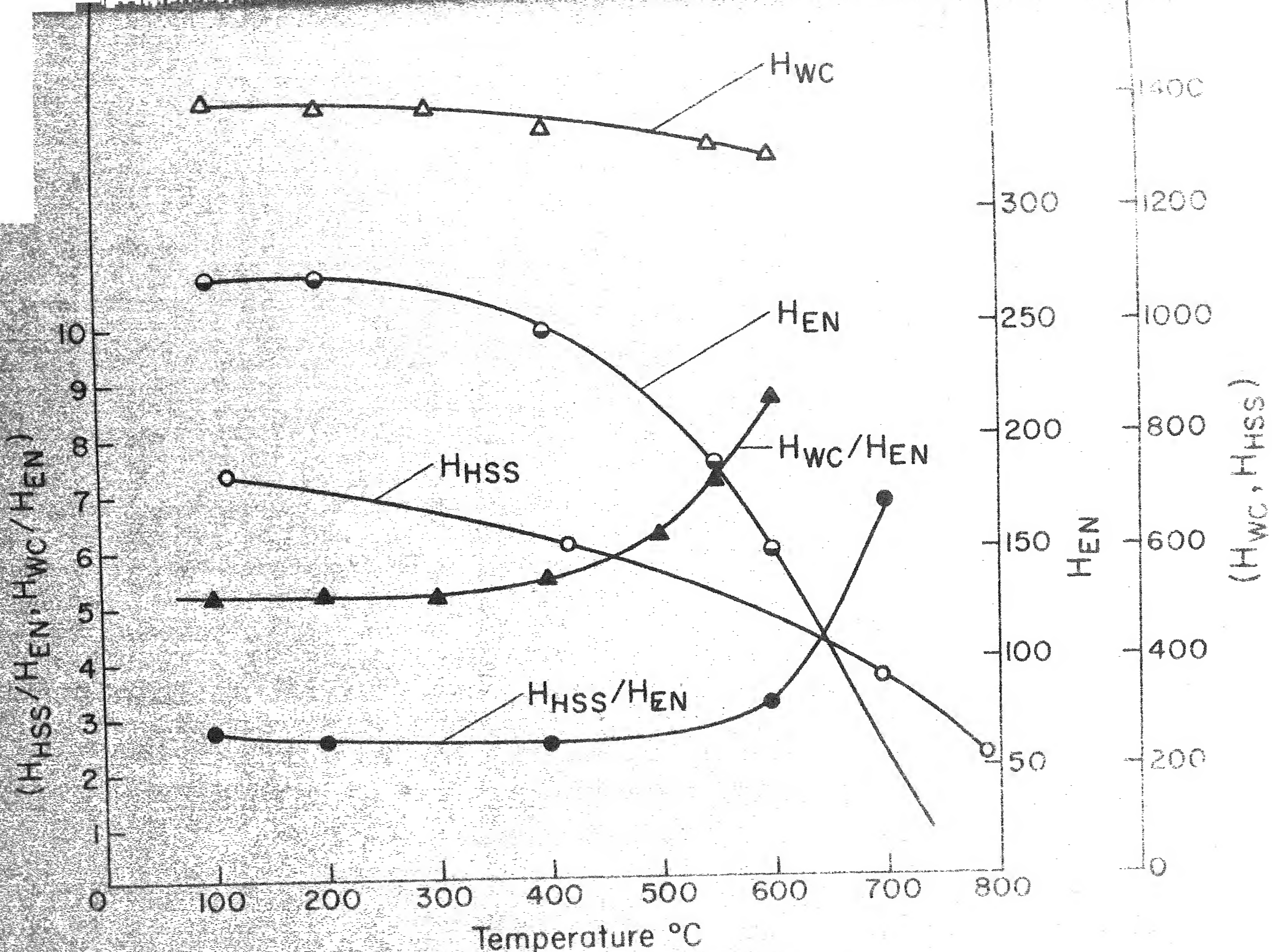

Fig.3.13 Variation of hardness with temperature (EN 24 Steel, Tungston carbide, HSS)

3.4.2 Friction Measurements of HSS Against En-24 Steel in Presence and Absence of Magnetic Field

As in the case of WC tools, friction coefficient was measured for HSS against En-24 steel also. Fig. 3.12 shows the variation of μ with various parameters. As can be seen from the figure the following trends:

1. friction coefficient is highest for conventional case (I = 0, M = 0)
2. friction coefficient is decreasing with increase in rubbing velocity
3. friction coefficient is further decreased with increase of heating current
4. in the presence of magnetic field the friction coefficient is increased.

The variation of friction coefficient with speed as observed in this case is quite similar to that of WC and has already been explained in Section 3.2.4.

There seems to be however, no easy explanation for increase in friction coefficient with magnetic field. No work seems to have been done on the effect of magnetic field on friction. In the present analysis it may be argued that magnetic field would strengthen the adhesion between the workpiece and the tool. Rabinowicz (18,19) has shown that the coefficient of friction between two sliding pair can be given by

$$\mu = \frac{\tau}{\sigma_y - \left[\frac{2E_{ab}\cot\theta}{r}\right]} \tag{3.4}$$

where, τ = shear stress at the interface

σ_y = flow pressure of the soft metal

r = indented radius (of asperity)

θ = base angle of a typical asperity.

In this expression E_{ab} is defined as the work of adhesion. It would be of interest to investigate how sensitive the work of adhesion is to the magnetic field. For, if E_{ab} gets increased by the application of magnetic field then, coefficient of friction should also increase. This would be an important problem worth further study.

There could be another possible reason for increase in friction coefficient with magnetic field. The reduction in wear of the cutting tool in presence of magnetic field due to more frequent failure of asperity junctions on the side of work piece (5,7). Such a situation is likely to result in relatively rough surface, hence greater mechanical inter locking of asperities. This could increase the coefficient of friction. However, more specific experiments are desired to be done in this direction, before any definite reason can be given.

3.4.3 Accuracy Calculations :

i) Force Measurements (Recording)

In the present experiments the lowest sensitivity used on the recorder is 0.005 v/cm. At this sensitivity one division on the chart represents 1 kg force. The nearest division we can read from the chart is 1/2 division and average no. of divisions representing the force was approximately 18 divisions.

Therefore, possible percentage of error = $\frac{1}{2x18} \times 100 = 2.78\% \approx 3\%$

ii) External force applied (by spring)

spring constant of the spring was 0.4 kg/mm

The relaxation in the spring due to wear of pin or tool is very small. Even the depth of wear is 0.25 mm the relaxation would be 0.1 kg in load. Therefore, this represents a percentage of error.

Percentage of error due to spring = $\frac{0.1}{18} \times 100 < 1\%$

iii) Wear Measurements

The accuracy in wear measurements can be analysed as follows. The minimum distance on the projector screen we can measure, is 0.01 mm. (i.e.) least count on the micrometer.

Average length of wear scar of WC = 0.3 mm

Average length of wear scar of HSS pins = 2 mm.

Therefore,

Percentage error for WC = $\frac{0.01}{0.3} \times 100 = 3\%$

Percentage error for HSS = $\frac{0.01}{2} \times 100 = 0.5\%$

CHAPTER IV

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

1. Application of magnetic field reduces the wear of tungstan carbide tools.

2. Superimposition of magnetic field on heating current is advantageous for a current of 50 and 100 amperes. Combination of 50 + Magnetic field as effective as 100 amperes.

3. The present work has idrntified the speed range and current which give the maximum gain of the tool. More cutting tests should be done in these ranges to establish usefulness in industry.

4. The rubbing wear results indicate the application of magnetic field is quite useful in hot machining. However, this aspect should be further analysed in this direction.

5. It is seen that wear rate does not increase with coefficient of friction. In fact it is seen that the wear rate is inversily proportional to coefficient of friction. It is interesting to see that Tomlinson's (28) hypothesis at molecular level and also predicts that wear rate is inversely proportional to friction coefficient.

6. Friction and wear is an important aspect of breaking systems. Generally, at high speeds the coefficient of friction is seen to be reduced. The reduced coefficient of friction is also associated with increasing wear rate. It is interesting to observe that in the present study, the coefficient of friction is seen to be increased by the application of magnetic field. And, such increase in friction is not limited to low speeds. Even at high speeds, coefficient of friction is increased by magnetic field. And, the wear rate is not increased. In fact it is decreased. This is evidently a great advantage and can be applied in breaking systems, with obvious advantage of higher friction coefficient with reduced wear. It is strongly suggested that series of experiments be conducted on the standard breaking materials which are magnetic in nature. This would be of immediate interest.

The present experimental set up doesnot strictly speaking permit to keep the load or nominal stress constant. Since the objective in this work has been to compare the same situation under the influence of magnetic field, this aspect is not very significant. However, to obtain more correct results individually it is desirable to have both normal load as well as nominal stress constant for a particular test. For this purpose a slightly different set up is required which should employ a dead weight through a lever mechanism. Also the material to be tested should be given same shape as rubbing surface (i.e. cylinder). Such studies would confirm the range of loads/stresses in which magnetic field is applicable.

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APPENDIX A

(i). Properties of En-24 Steel[29]:

Nominal composition (3) :

C, 0.35-0.45; Si, 0.10-0.35; Mn, 0.45-0.70;

S, 0.50 max ; P, 0.05 max ; Ni, 1.30-1.80;

Cr, 0.90-1.40; Mo, 0.20-0.35

Tensile strength tons/sq.in.min : 50 (softened condition)

Brinell hardness No. : 223/277 (softened condition)

Machinability: Approximately 53% of mild-steel

(ii). Properties of Carbide Tool Material :

Composition (%)

WC, 0.76; Co, 0.08; TaC, 0.04; TiC, 0.12.

Abrasion resistance	:	Low
Impact resistance	:	High
Crater resistance	:	High
Young's modulus	:	90×10^{-6} psi
Rockwell Hardness "A" Scale	:	92
Hot working tempera ture	:	Retains hardness upto 1000°C approximately.

APPENDIX B

The required normal load N to be applied for the workpiece to be just under - plastic deformation at the tool work interface was roughly estimeated as follows:

The contact zone between the cylindrical workpiece and the nose of the tool bit would be elliptical in shape and of area A

$$A = \pi ab$$

where, a,b are the semi-axes of the ellipse.

Also, for small δ, $a^2 \simeq 2R\delta$

$$b \simeq 2\rho\delta$$

where,

R = radius of the workpiece

δ = depth of indentation

ρ = nose radius of tool bit

Therefore,

$$A \simeq 2\pi\delta\sqrt{R\rho}$$

Now, ρ = 1.58 mm (for standard tool nose radius = $\frac{1''}{16}$)

R = 70 mm (for the workpiece used).

When the tool job interface was just loaded (radially) enough to initiate the plastic deformation of the workpiece, it was seen that

$$a \simeq 0.105 \text{ mm}$$

Therefore, from equation

$$\delta = \frac{a^2}{2R} = \frac{0.105^2}{2 \times 35} = 1.575 \times 10^{-4} \text{ mm}$$

$$\therefore \quad b^2 \simeq 2 \rho \delta \quad 25 \times 10^{-6} \text{ mm}^2$$

$$b \simeq .005 \text{ mm}$$

then, $$A = 0.0735 \text{ mm}^2$$

Thus the force N required to create this contact area of A

$$N = A.\,H$$

$$= 0.0735 \times 250 = 18.375 \text{ kg}$$

In the test a load of 18 kg. was found to be quite appropriate, to be used.